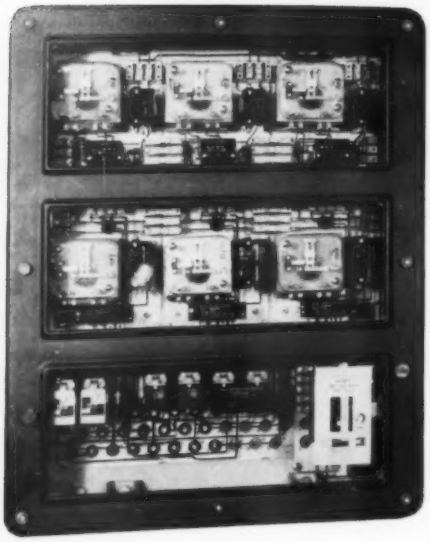
TEXAS ENGINEERS LIBRARY
COLLEGE STATION, TEXAS
MAY 2 6 1961

Making final preparations to
a Kaplan runner
before placing in position.

Boving *WATER TURBINES*

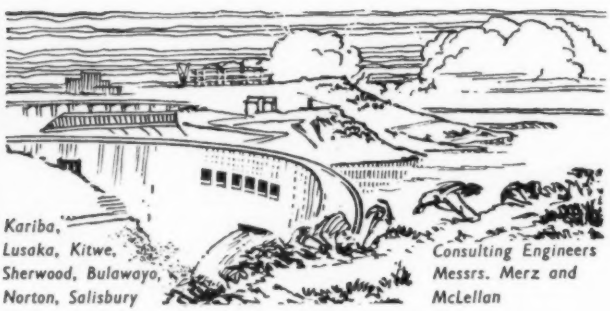
power the WAIPAPA N.Z. hydro-electric station

BOVING & CO LIMITED VILLIERS HOUSE 41-47 STRAND LONDON W.C.2



KARIBA

330-kV Transmission System Protected by Reyrolle Type-H Distance Protection



Kariba, Lusaka, Kitwe, Sherwood, Bulawayo, Norton, Salisbury

Consulting Engineers Messrs. Merz and McLellan

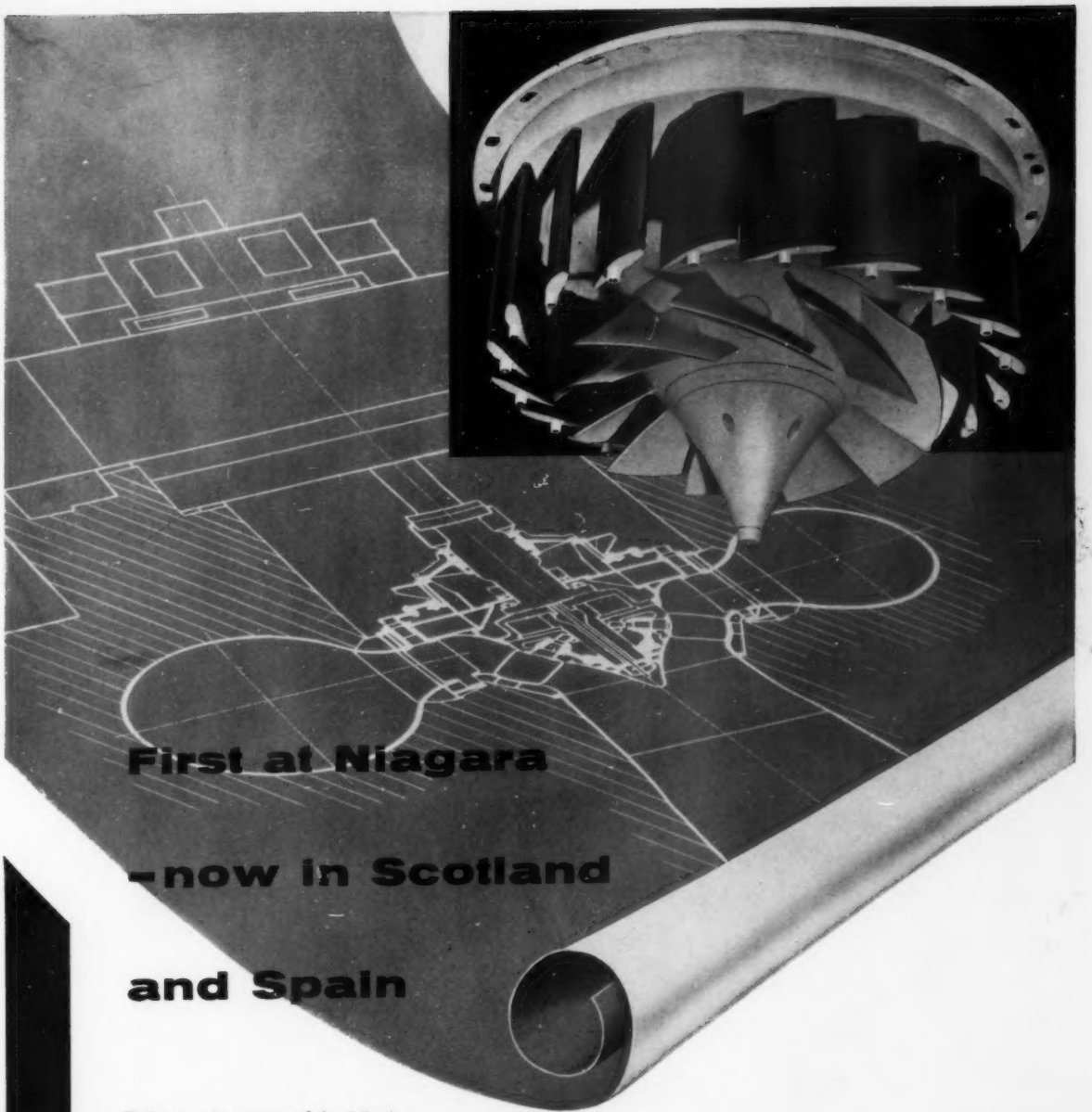
Reyrolle type-H high-performance distance protection incorporates the following important features:

- High speed for all types of fault
- Accurate measurement for exceptionally wide range of source to line impedance
- Negligible over-reach on D.C. transients
- Separate moving-coil elements for earth-faults and phase-faults
- All relay-elements identical and easily removable
- Self-contained design reduces panel wiring
- Built-in phase-selectors for single-phase auto-reclosing if required

Applied to major transmission lines throughout the world

Reyrolle

A. REYROLLE & COMPANY LIMITED - HEBBURN - COUNTY DURHAM - ENGLAND



First at Niagara

–now in Scotland

and Spain

Following the success of the 6 Deriaz reversible pump turbines at Niagara, a 30,500 h.p., 180 feet head Deriaz turbine coupled to a 22 MW alternator has been ordered for the Culligran Power Station of the North of Scotland Hydro-Electric Board. Three—110,000 h.p., 242 ft. head Deriaz reversible pump turbines have been ordered by Hidroelectrica Espanola for the Valdecanas Power Station on the River Tagus, coupled to 83,333 kVA semi-umbrella alternators.

'ENGLISH ELECTRIC'

hydro-electric equipment

THE ENGLISH ELECTRIC COMPANY LIMITED, ENGLISH ELECTRIC HOUSE, STRAND, LONDON, W.C.2

Hydro-Electric Department, Dunnings Bridge Road, Netherton, Bootle, 10

WORKS: STAFFORD · PRESTON · RUGBY · BRADFORD · LIVERPOOL · ACCRINGTON

HE.38A

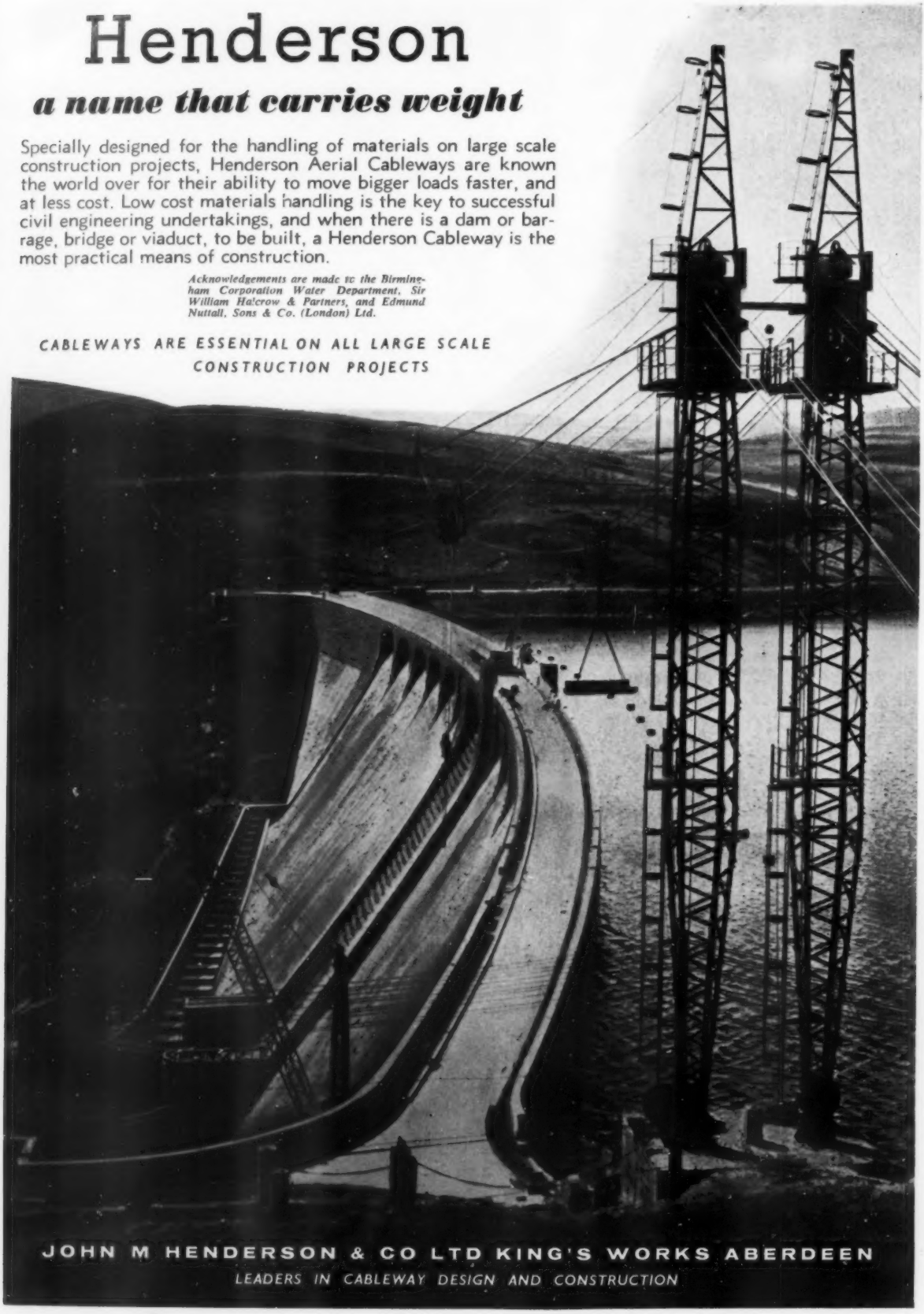
Henderson

a name that carries weight

Specially designed for the handling of materials on large scale construction projects, Henderson Aerial Cableways are known the world over for their ability to move bigger loads faster, and at less cost. Low cost materials handling is the key to successful civil engineering undertakings, and when there is a dam or barrage, bridge or viaduct, to be built, a Henderson Cableway is the most practical means of construction.

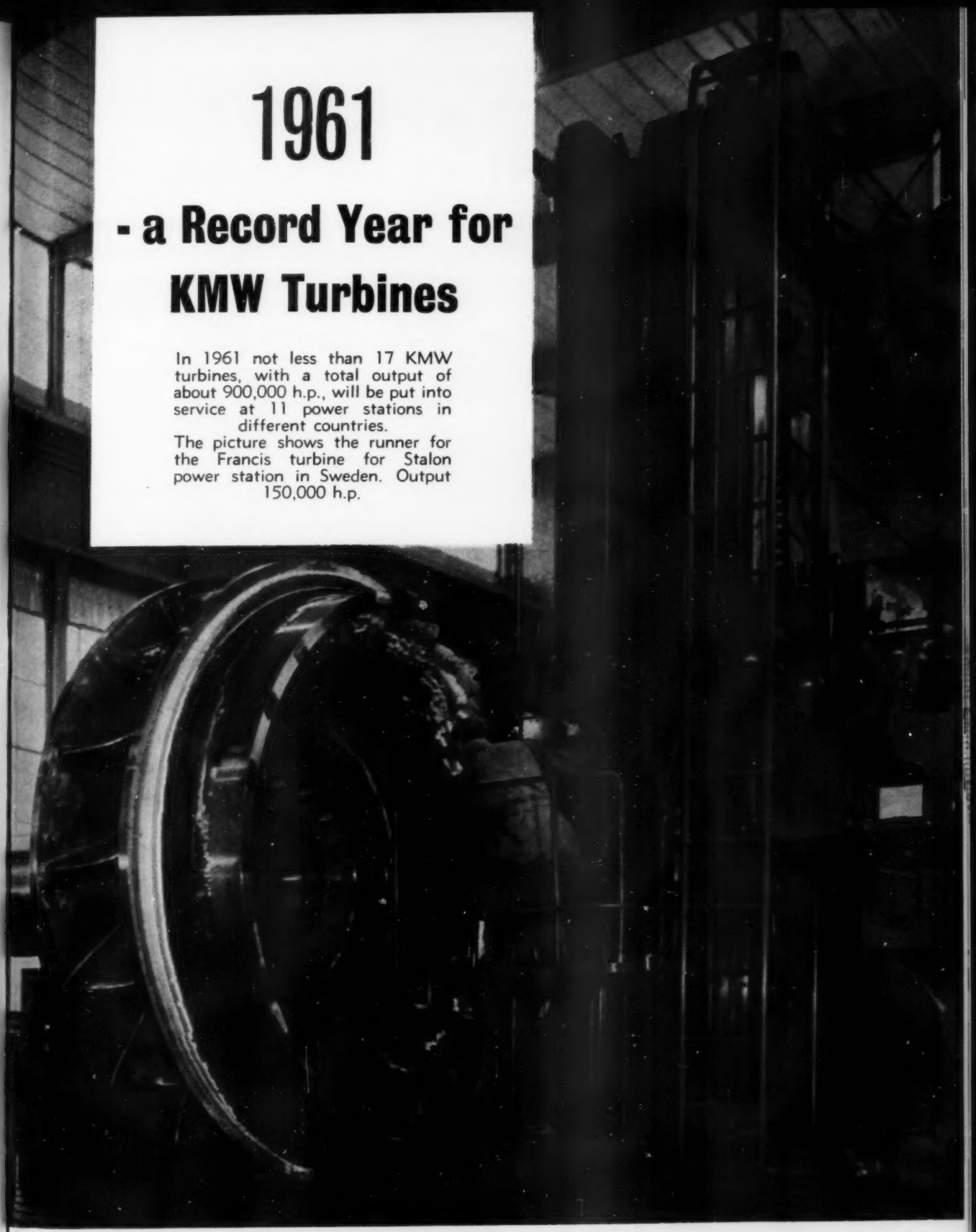
Acknowledgements are made to the Birmingham Corporation Water Department, Sir William Halcrow & Partners, and Edmund Nuttall, Sons & Co. (London) Ltd.

CABLEWAYS ARE ESSENTIAL ON ALL LARGE SCALE CONSTRUCTION PROJECTS



JOHN M HENDERSON & CO LTD KING'S WORKS ABERDEEN

LEADERS IN CABLEWAY DESIGN AND CONSTRUCTION



1961

- a Record Year for KMW Turbines

In 1961 not less than 17 KMW turbines, with a total output of about 900,000 h.p., will be put into service at 11 power stations in different countries.
The picture shows the runner for the Francis turbine for Stalon power station in Sweden. Output 150,000 h.p.

AB KARLSTADS MEKANISKA WERKSTAD

KARLSTAD - SWEDEN

Representatives in Canada: A. Johnson & Co. Ltd., P.O. Box 56, Montreal 16

KMW

SCARPA E MAGNANO

POTENTIAL TRANSFORMERS

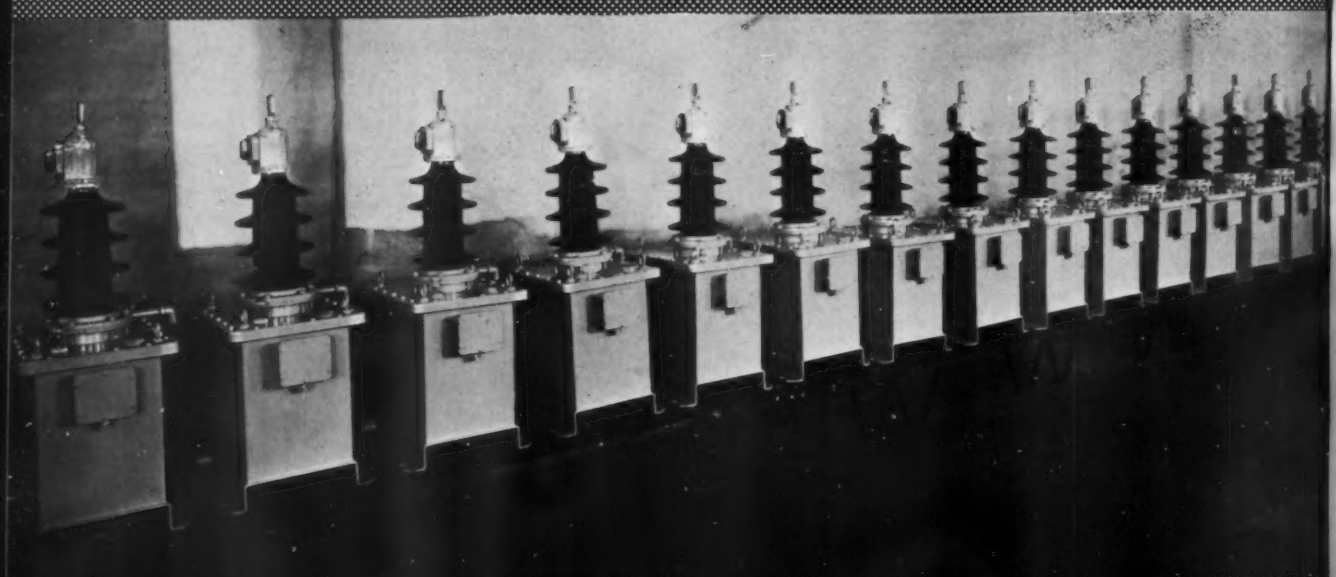
FOR RATED VOLTAGE FROM 11 TO 245 kV

Potential transformers manufactured by Scarpa e Magnano have been specially designed to have a very small oil content.

The primary winding is insulated by means of a continuous oil impregnated paper wrapping, which ensures high dielectric and mechanical withstand.

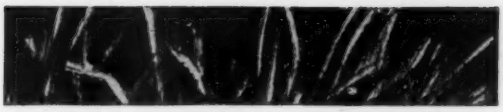
During the oil filling process, the transformer oil and the winding insulation undergo a special vacuum treatment.

33 kV Potential Transformers for New Zealand Electricity Department



small - oil - volume circuit breakers
metal - enclosed air - insulated switchgear
instruments and protective transformers
isolators switchboards and control desks

SCARPA e MAGNANO - VIA MANZONI, 12 - MILANO (ITAL

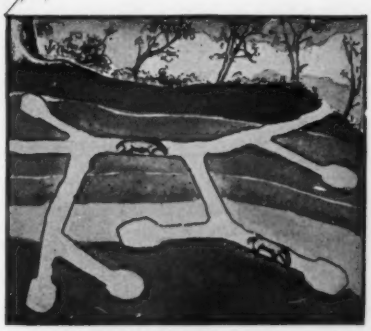


Underground movement

A long tunneller and a strong tunneller, the badger builds himself an intricate web of passages and dens in which to evade pursuit or retire from the noisy world outside.

It's a paradox of progress that man too—in getting even further away from nature—is going more and more underground. Tunnels for hydro-electric schemes, underground power houses—these and many other engineering feats are the work of man the tunneller—a skill which we have developed into a fine art. * *

* * In driving 45 miles of tunnels for the North of Scotland Hydro-Electric Board, Mitchell Construction captured and hold the World high speed rock-tunnelling record and constructed the first major underground power station in Britain.



Many of these badger 'sets' have been enlarged and improved through successive generations and may extend for hundreds of feet into a hillside.

MITCHELL CONSTRUCTION

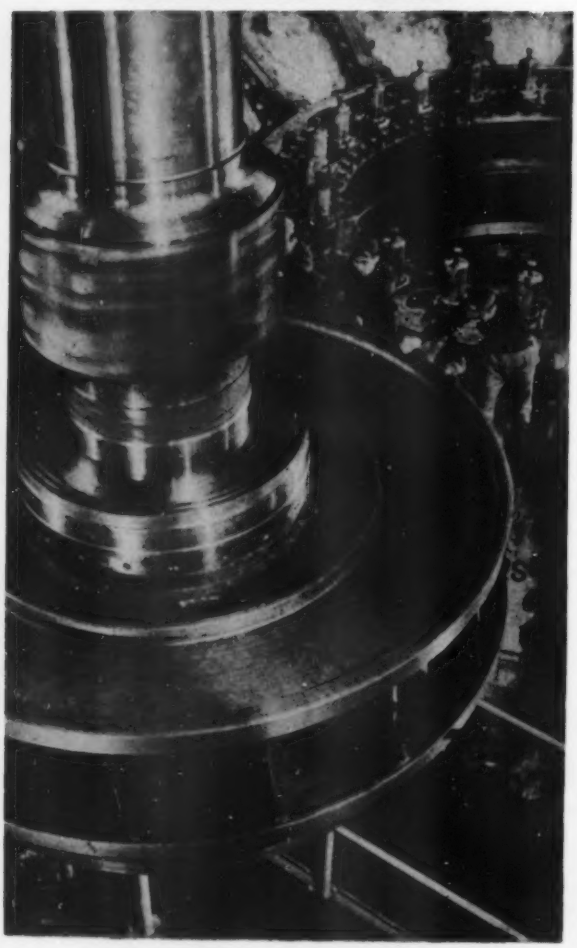
Building and Civil Engineering Contractors

THE MITCHELL CONSTRUCTION COMPANY LIMITED

WHARF WORKS · PETERBOROUGH

P.3784

Toshiba



Contributing to Your Better Living!

Heavy electric equipment such as Water Turbines, Generators, Power Transformers, and testing equipment for Power Stations, are being shipped out one after another from Toshiba's Tsurumi works.

Shown above is one of the 3 scheduled 133,000 kVA generators—among the largest in the world—to be installed at Okutadami Power Station in central Japan.

The 137,000 KW Francis turbine, seen at left, to be coupled with this generator is also a Toshiba product. The runner diameter of this turbine is 4,000 mm, and ranks among the biggest in the world.

Similar generators with 58,000 kVA power has been installed at Mazatepec Power Station in Mexico and is now in full operation, Toshiba is also in production for various heavy equipment for many other new projects around the world.

Tokyo Shibaura Electric Co., Ltd.

2 Ginza Nishi 5-Chome, Chuo-ku, Tokyo, Japan
Cable Address: TOSHIBA TOKYO

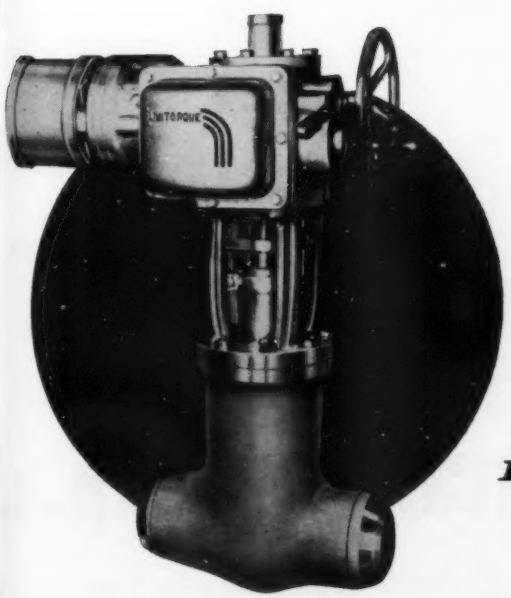
SAVE

TIME

LABOUR

MONEY

switch to *LIMITORQUE* push-button valve control



To-day, in industries where liquid has to be controlled, more and more people are converting their hand-operated valves to LimiTorque. For with LimiTorque, the actuator with push-button control, one man does the work of many—simply and efficiently. What does switching to LimiTorque entail ? In almost every case, no more than minor changes to the valve. Highly sensitive and automatic, LimiTorque is easily adapted for use with all types of valve.

***LIMITORQUE* VALVE CONTROLS LTD**

NEWBURY · BERKSHIRE

Tel: Newbury 1701 · Grams: LimiTorque Newbury

AN ASSOCIATED COMPANY OF OPPERMAN GEARS LIMITED

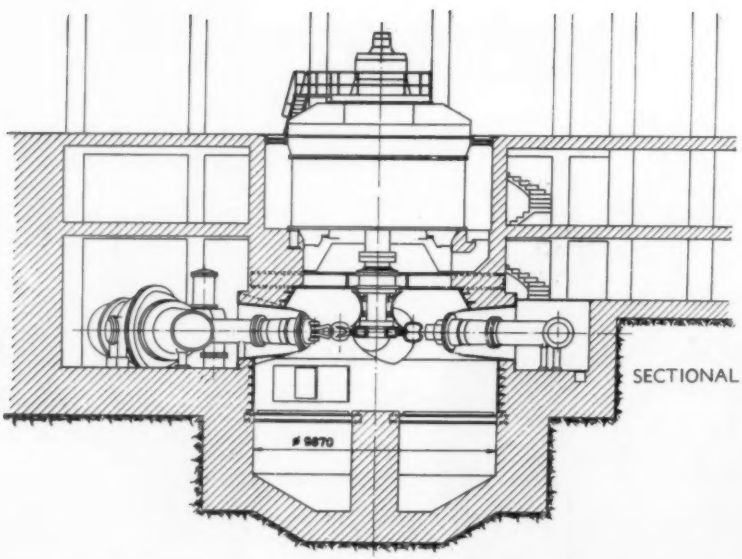
This picture shows a completely assembled Rotary Valve during its final machining stage

AZIENDA
ELETTRICA
MUNICIPALE
MILANO (ITALY)

GROSIO Water P

2—107,000 kW.
VERTICAL AXIS,
FOUR-JET
PELTON UNITS

EUROPE'S HIGHEST OUTPUT PER UNIT



SECTIONAL AND PLAN VIEW OF

FRANCO TOSI S.p.a. L

Power Station

NORTH ITALY

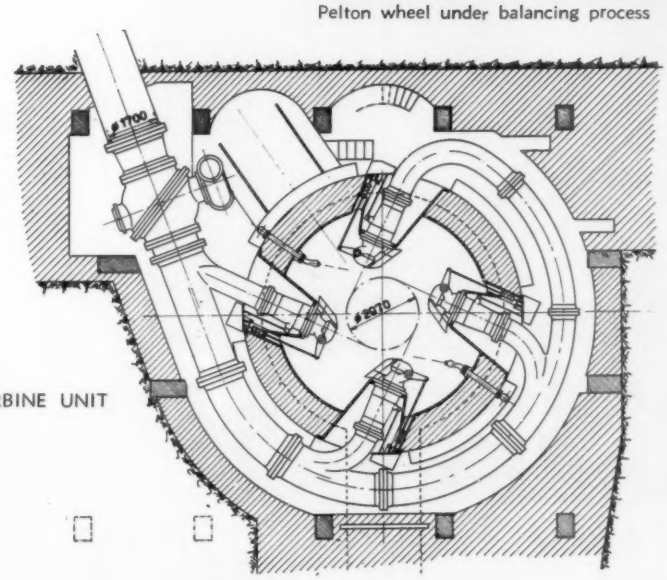
Output each: 107,000 kW.

Available head: 600 mts.

Discharge: 20,350 lts./sec.

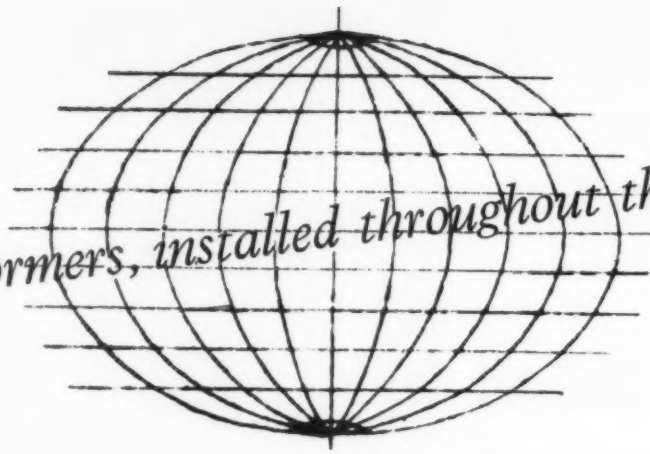
Speed: 333.33 r.p.m.

Pelton wheel under balancing process



VIEW OF A PELTON TURBINE UNIT

LEGNANO (ITALY)



YORKSHIRE TRANSFORMERS

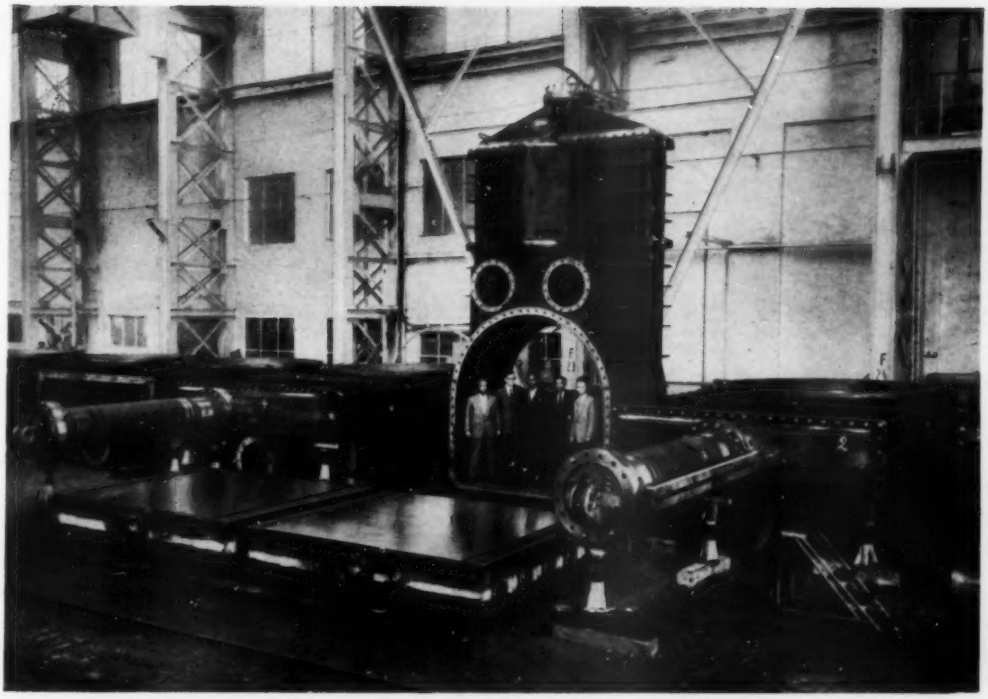
132kV

YORKSHIRE

YORKSHIRE ELECTRIC TRANSFORMER CO. LTD.,
THORNHILL, DEWSBURY, YORKS. TEL: 1691-2 'GRAMS: 'TRANSFORMA, DEWSBURY'

M·A·N

1349

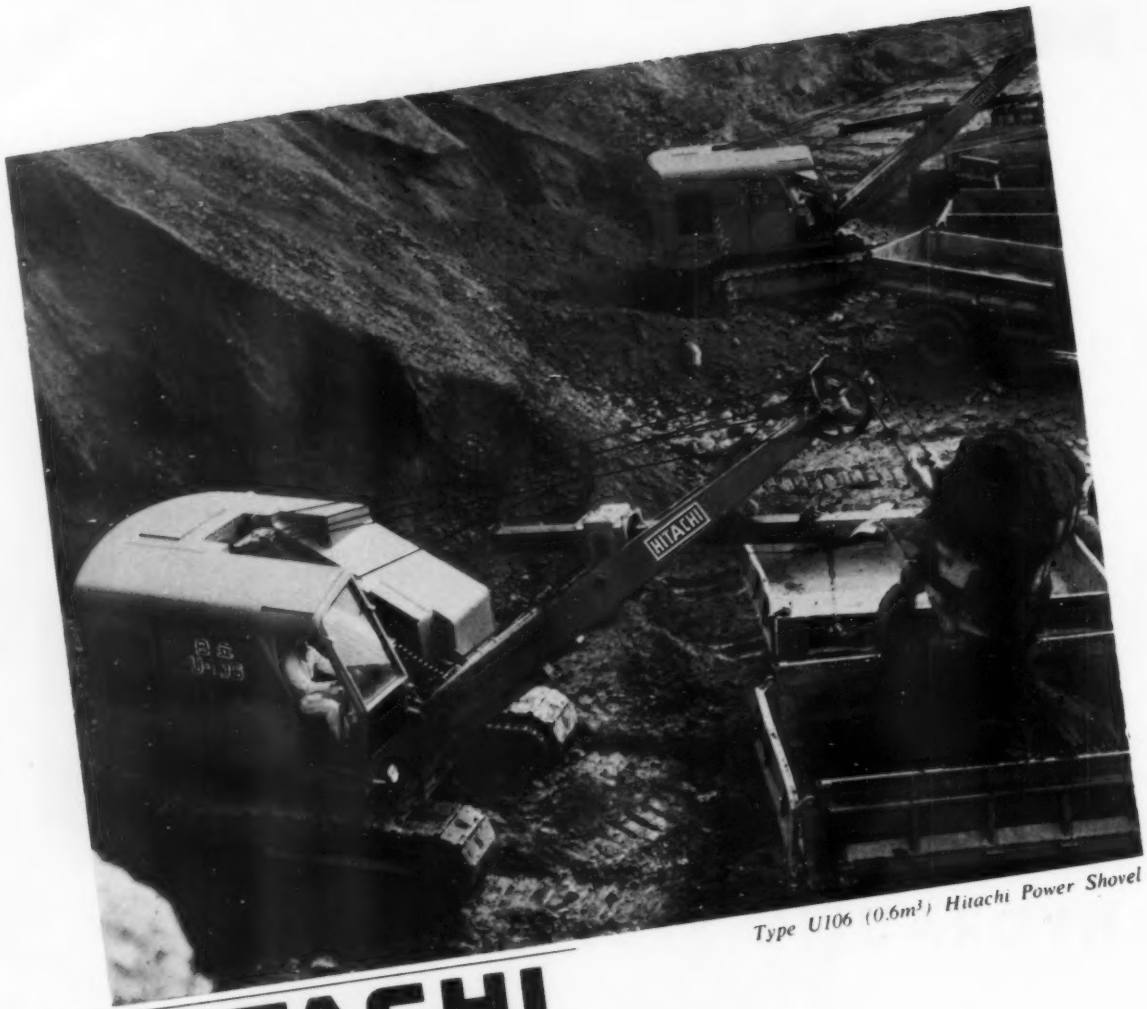


HYDRAULIC STRUCTURES

Jet-flow deep-gates as regulating gates for highest velocities of flow allow of operation free from both cavitation and vibration.

8 jet-flow gates 2.44 m dia. for 110 m water head for Bhakra/India in the course of shopwork.

MASCHINENFABRIK AUGSBURG-NÜRNBERG AG · GUSTAVSBURG WORKS
GUSTAVSBURG/HESSEN (GERMANY) · REPRESENTATIVES IN ALL COUNTRIES



Type U106 (0.6m³) Hitachi Power Shovel

HITACHI CONVERTIBLE SHOVEL

There's little glamour about a machine designed for engineers by engineers—men who are unsatisfied with anything less than constant, top efficiency.

The rugged Hitachi Convertible Shovel has been built for smooth and fast operation under the toughest conditions, from the tips of its wear-resistant cast steel dipper teeth to its stable, extra long and wide truck frame. The versatile Hitachi Convertible Shovel offers a choice of diesel engine or electric induction motor as prime mover, can be mounted on crawlers or truck for still higher mobility. The efficient Hitachi Convertible Shovel converts quickly and readily to dragline, drag shovel, clamshell, crane or piledriver. Literature and quotations gladly supplied on request.

Hitachi, Ltd.
Tokyo Japan
Cable Address: "HITACHY" TOKYO

One of the most important hydro-electric power stations

An interior view of the Caroní-Macagua machine hall

Rio Caroní before the power-station was built

One of the most important hydro-electric power stations is now under construction on the lower reaches of the Rio Caroní in Venezuela.

AEG

With its six 70 MVA, 116 rev/min AEG umbrella-type alternators it will furnish power for a vital industrial centre being developed in an area rich in resources.

8870e

ALLGEMEINE ELEKTRICITÄTS-GESELLSCHAFT

Berlin (West) EXPORT DEPARTMENT Frankfurt (Main)

A NAME WITH POWER BEHIND IT

From the huge auto-transformers that bear our name, the cables stretch in many directions to link with yet more Ferranti equipment. Some connect with power station controls and switchgear. Others carry on across country to meet further transformers of lesser degree. All terminate, in one way or another, with some form of metering device. United, these Ferranti products play a vital part in the British 'grid' system and in the supply of electricity all over the world.

And, like them, we at Ferranti never cease working in the interests of those who generate or consume electricity. Even as you read these words, Ferranti technicians are waging a battle against transformer noise. They are devising methods to enable mammoth transformers to be taken from works to site with the minimum of traffic inconvenience. They are developing new and improved forms of meters, measuring instruments, switches, control gear and testing equipment.

In the future, as for the past seventy-five years, Ferranti will always be an outstanding name wherever there is power in the land.

FERRANTI

First into the Future

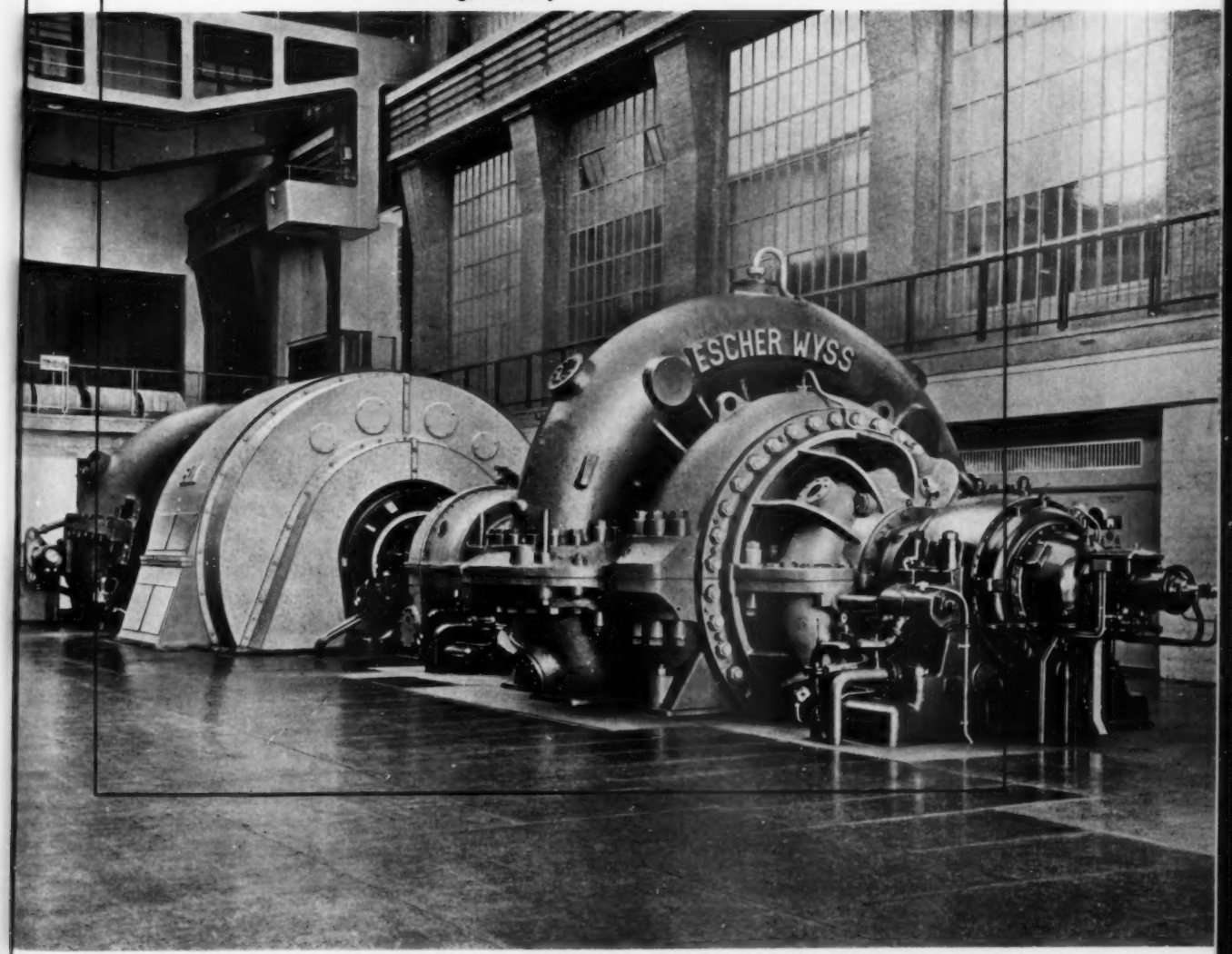
Ferranti Ltd., Head Office: Hollinwood, Lancs. London Office: Kern House, 36 Kingsway, W.C.2

ESCHER WYSS

20 Storage Pumps with a total input of 850 000 HP

Escher Wyss manufacture the complete hydraulic equipment for Storage Power Plant
These installations are becoming of increasing importance due to the advantages they offer in dealing with peak load of thermal power plant, whilst utilizing the surplus energy of the latter during periods of reduced current consumption

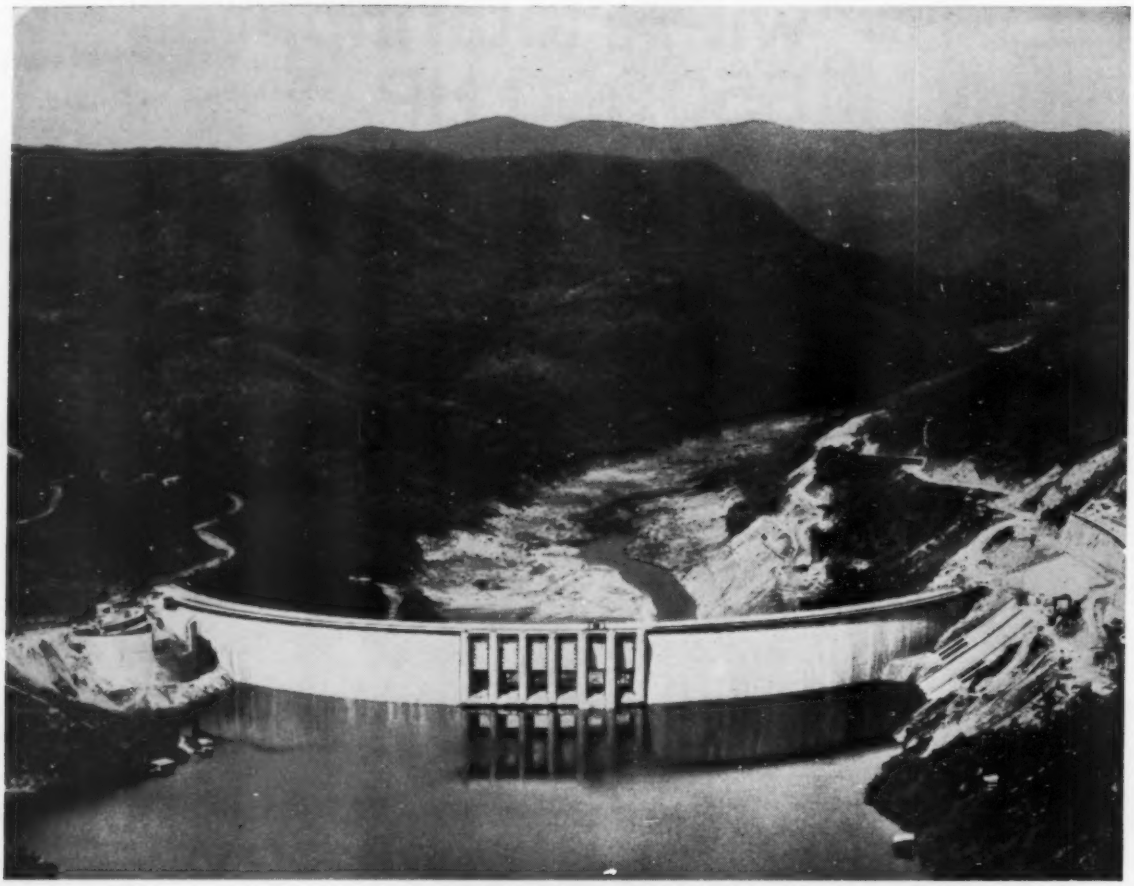
Our European works are at present manufacturing 20 Storage Pumps with inputs totalling approx 850 000 HP for installations in Germany, Italy, Luxembourg, the Near East and Switzerland. They include two 93 000 HP units for Vianden/Luxembourg and two 91 700 HP units for Villa Gargnano/Italy



Storage Power Plant at Limberg/Austria for which we supplied 2 Francis Turbines each developing 77 000 HP under 364 metres and 2 Storage Pumps for heads of 320–420 metres with inputs of 85 000 HP per unit

Escher Wyss Ltd., Zurich/Switzerland

KARIBA



Consulting Electrical and Mechanical Engineers: Messrs. Merz and McLellan

and AEI

Six 100-MW generators for Stage One of the massive hydro-electric project at Kariba, on the Zambesi river, have been supplied by AEI. They are the largest hydro-electric generators in the entire continent of Africa.

AEI Associated Electrical Industries Limited

HEAVY PLANT DIVISION RUGBY ENGLAND

A5552

Penstock and Gate

We specialize in . . .

DESIGNING
MANUFACTURING
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Established: 1904

SAKAI IRON WORKS CO., LTD.

HEAD OFFICE: NISHI, 6-CHOME, TSUMORI-CHO, NISHINARI-KU, OSAKA, JAPAN CABLE ADDRESS: "SAKATETSU OSAKA"

TOKYO OFFICE: NIHONBASHI-GOFUKUBASHI, CHUO-KU, TOKYO, JAPAN CABLE ADDRESS: "SAKATETSU TOKYO"

LOCH GIORRA DAM

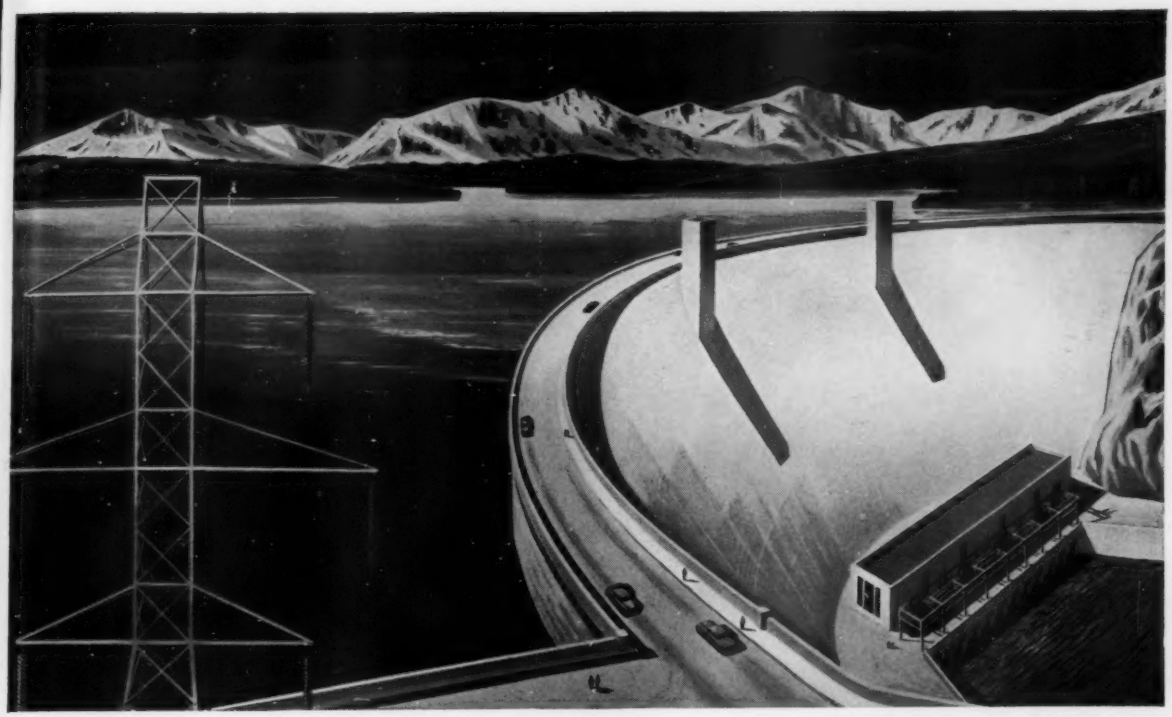
The new Giorra Dam shown below was built by Edmund Nuttall, Sons & Co. (London) Ltd., for the North of Scotland Hydro-Electric Board. The dam, which is 1,450 feet long and 100 feet high, stands at the eastern end of Loch Giorra and forms an important part of the Breadalbane Power Scheme.

Authority: North of Scotland Hydro-Electric Board
Consulting Engineers: James Williamson & Partners

EDMUND NUTTALL

CIVIL ENGINEERING CONTRACTORS

EDMUND NUTTALL SONS & CO. (LONDON) LTD. 22 GROSVENOR GARDENS, LONDON S.W.1 PHONE: SLOANE 0036



KULJIAN . . . SPECIALISTS IN POWER

4,000,000 KILOWATTS . . . that's the total generating capacity represented by the more than 100 Kuljian power projects now in operation throughout the world. Kuljian engineers are specialists in power—qualified by experience to design, engineer and supervise construction of hydroelectric, steam, internal combustion and nuclear power plants and associated facilities.

Every Kuljian hydroelectric project combines the skills and experience of a complete staff of internationally recognized experts in all phases of water resources development. No matter what your next power project might be, The Kuljian Corporation is fully prepared to undertake efficiently all phases of design, engineering, and construction supervision to help bring about the quick, economical solution to your specific problem.

- **Surveys**
- **Investigations**
- **Reports**
- **Reservoirs and Dams**
- **Hydroelectric Power Stations**
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The **Kuljian** *Corporation*

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1200 NORTH BROAD STREET • PHILADELPHIA 21, PA., U. S. A.

HYDROELECTRIC DIVISION

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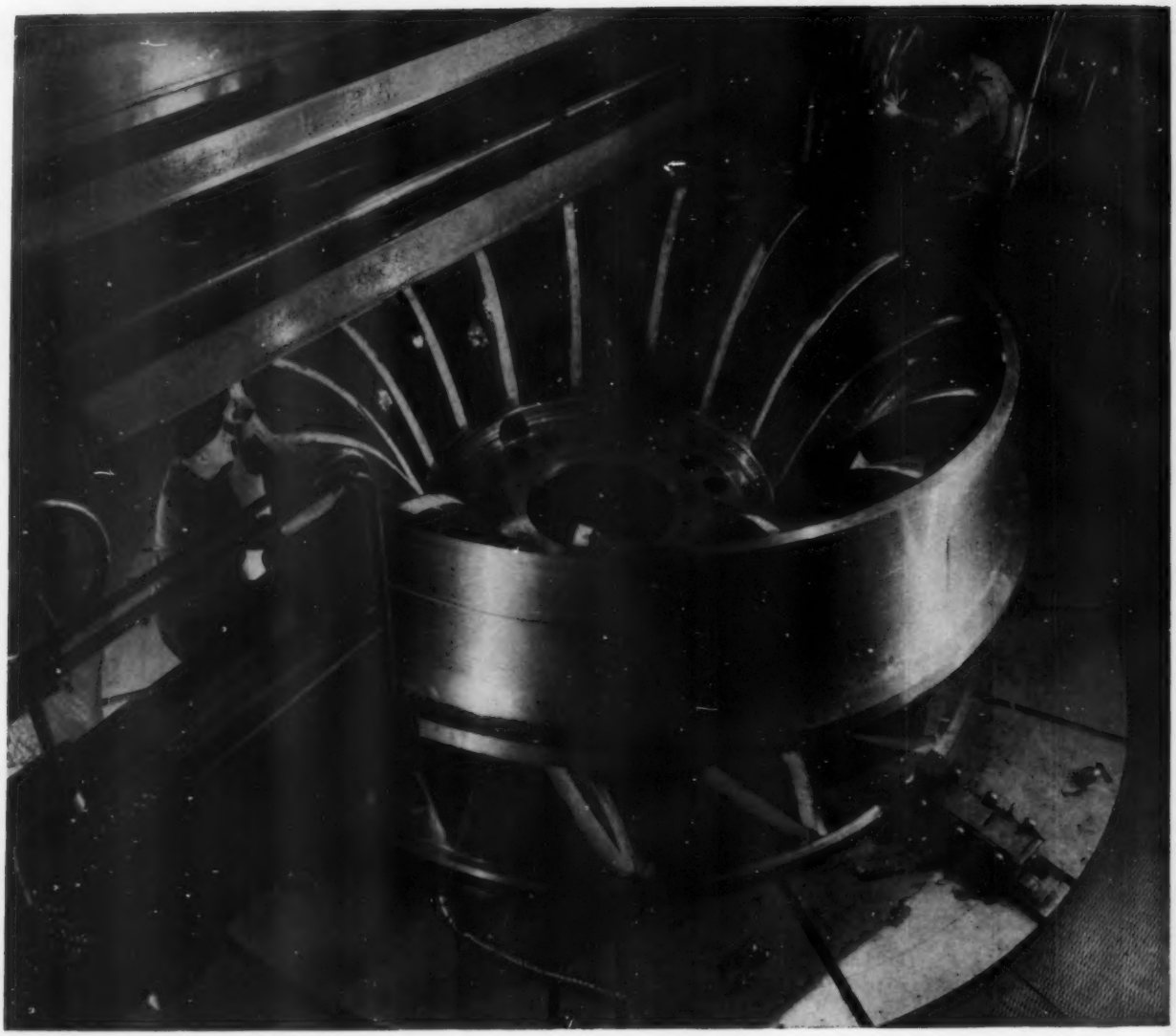
DESIGN • ENGINEERING • PROCUREMENT • CONSTRUCTION • REPORTS



ALDEADAVILA - Spain

6 vertical-shaft Francis turbines
Output 125 000 kW — Head 139 m
Speed 187.5 rpm.

Hydraulic and mechanical equipment for power stations and dams « Neyrfor » drilling equipment. Hydrodynamic transmissions. High-output fans (Stork licence). Hydraulic conveying and grading plant. Mechanically synchronised hydraulic bending presses. Equipment for irrigation and water supply systems. Wind-driven machinery Hydraulic measuring equipment. Equipment for hydraulics laboratories. Special equipment for nuclear engineering Assembling, welding and machining of large and complicated components.

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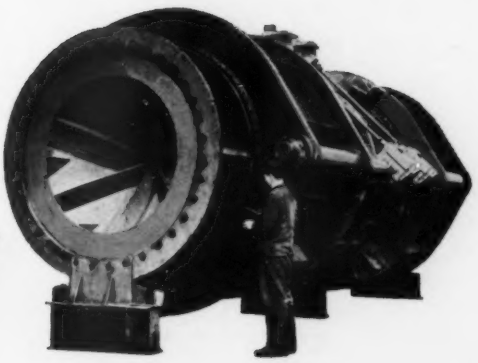
SPÉCIALISTS IN LIGHT AND HEAVY ENGINEERING

RHEINSTAHL
UNION BRÜCKENBAU AG

Two Howell-Bunger Valves, 7' dia, for the Yan-Hee Dam, Thailand, with a capacity of 4800 cusec discharge under normal waterhead of 400'. Test pressure is 490'.
Illustrated is the preassamblage of the two valves for pressure testing.



Preassamblage of one of three radial gates for the Derbendi Khan Dam, Iraq.
These gates, 50' wide and 52' high, are to withstand a waterpressure of ca 2300 metr. tons each. They are the largest gates of this type ever built.

Since more than 50 years
RHEINSTAHL UNION BRUCKENBAU
is engaged in designing and supplying steel structures for many important Hydro-electric schemes.

The programme of production comprises

Deep sluice gates and valves for intakes and outlets
Automatic and man-operated weir gates and crest gates for dams

Dock gates and regulator gates, also
High pressure pipelines with branch-offs and bifurcations

The programme further includes the construction of

Hoist equipment
Servo motors
Gantry cranes and the like

as necessary for the operation of the gates and valves.

RHEINSTAHL UNION BRUECKENBAU AG., DORTMUND, WEST-GERMANY

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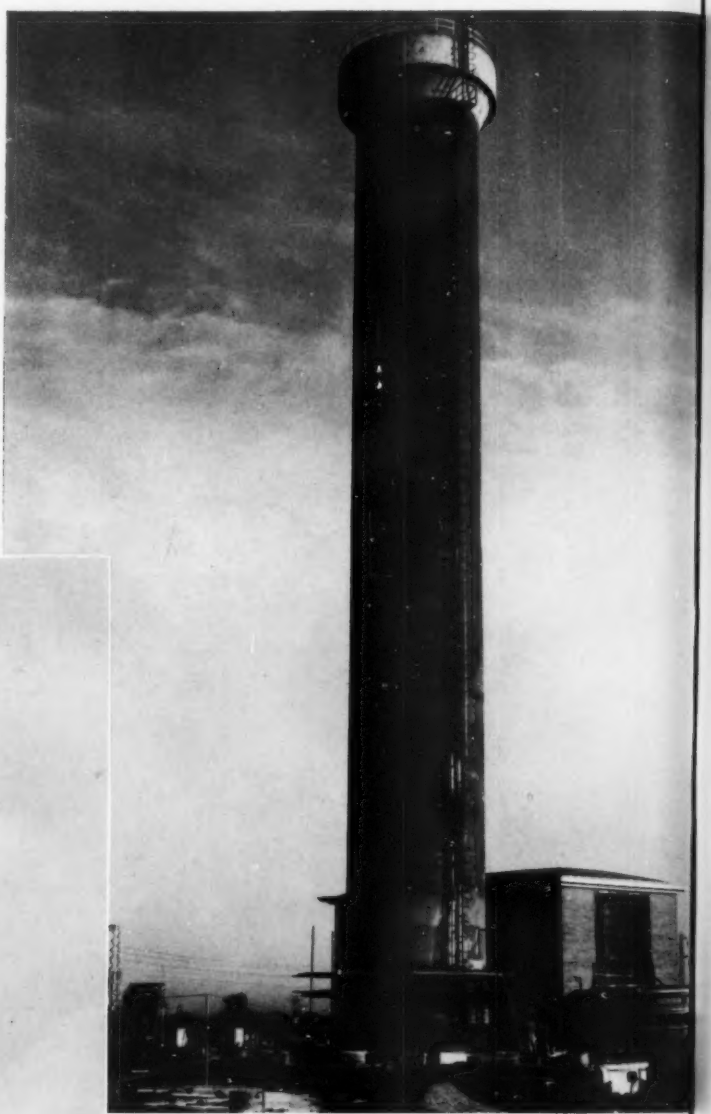
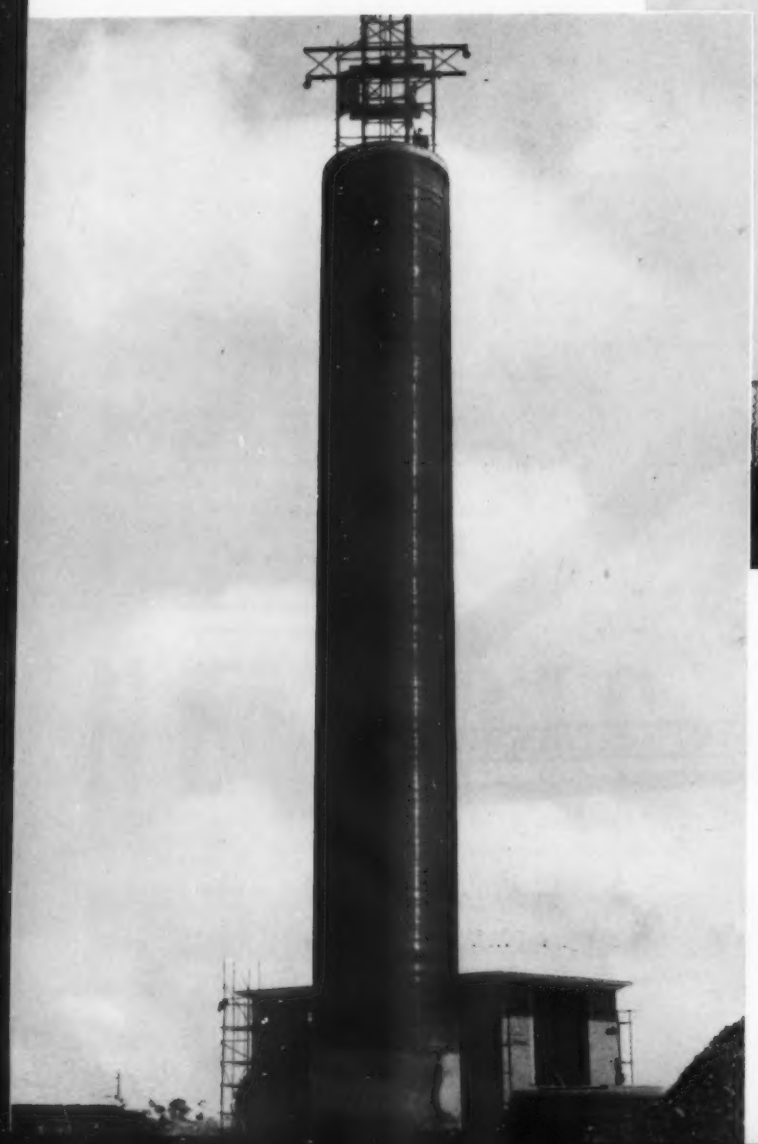
VENICE (ITALY) - Accademia 979/A - Telephone 85.060

Normal, special and prestressed reinforced concrete Penstocks of any diameter and pressure.



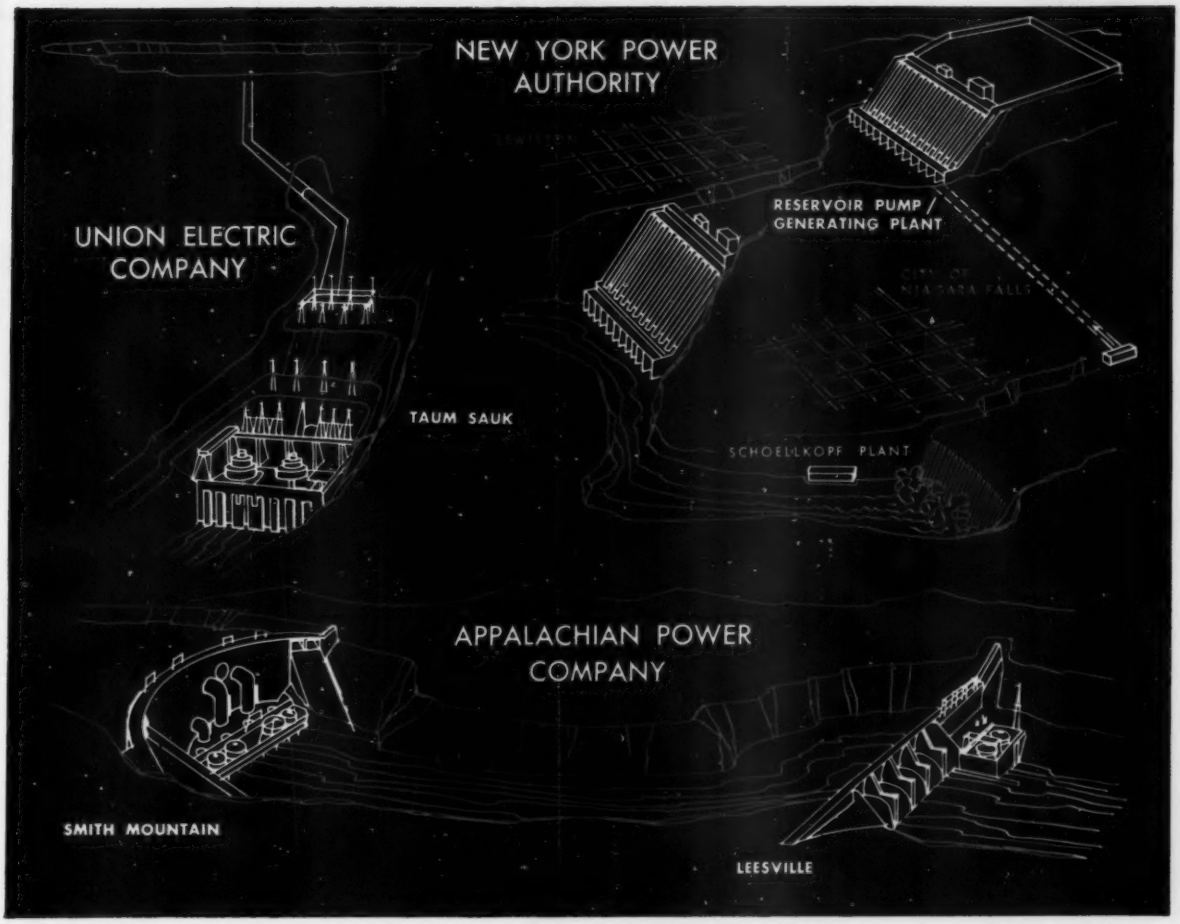


SURGE TOWER in prestressed reinforced concrete (Diameter 6 metres, Height 60 metres) for the MEDUNA Hydro-electric Station of

S.A.I.C.I.

SOCIETA AGRICOLA INDUSTRIALE PER LA CELLULOSA ITALIANA DI MILANO

ALLIS-CHALMERS



Just what you'd expect from the pumped-storage pioneer:

first in all three

Pumped-storage power projects now under construction in this country all rely on Allis-Chalmers reversible pump-turbines. In fact, A-C is the only builder of complete reversible pump-turbine equipment!

First in boosting existing hydro at Niagara Reservoir pump/generating plant! This pumped-storage project will capitalize on the hydro-electric power potential of Niagara River without adversely affecting the scenic beauty of the Falls. Largest project of its kind, this installation will include 12 reversible pump-turbines with motor-generators . . . all designed and fabricated by Allis-Chalmers. As a turbine, each unit is rated 28,000 hp under 75-ft net head; as a pump, 3,400 cfs at 85-ft total head.

First in pure regeneration — at Taum Sauk! . . . also to have the largest-capacity hydro units ever built. Allis-Chalmers will supply two 175,000 kw reversible pump-turbines, each with a capability exceeding 300,000 hp under 800-ft head. (Pure regeneration installations need only a water supply to replace evaporative losses, so a creek is ample. Even a hill is unnecessary: the pool can be underground, in an abandoned mine shaft, for example.)

First in run-of-river — at Smith Mountain! This new project involves reservoirs at two successive levels, the lower dam forming a tailrace pool at the upper dam for two A-C reversible pump-turbines, each rated 87,000 hp at 180-ft head. Conventional hydro-generating units will also be installed — two higher-head units at the upper dam and two lower-head units at the lower dam.

For complete information on pumped-storage, hydro-generating equipment or other components for water control, contact your nearby A-C office. Or write to **Allis-Chalmers,** *Hydraulic Division, York, Pa.* A-1385

Outside United States contact Allis-Chalmers International, or in Canada, Canadian Allis-Chalmers

FOR THE WORLD'S HIGHEST VOLTAGE

One of the poles of a series of 525 kV, 15,000 MVA, AE 2 air blast circuit breakers, for the equipment of the U.R.S.S. network.

the air blast circuit breaker

type AE

A range of breakers
from 70 kV to 525 kV
Breaking capacity :
30,000 amp. rms.

Besides properties peculiar to the technique of air blast circuit breakers the type AE apparaters provides :

- Breaking with high r.r.r.v. and ability to interrupt a kilometric fault.
- Breaking of currents in unloaded power transformers with low overvoltages
- Low air consumption.
- Negligible burning of contacts.

Ateliers de Constructions Electriques de

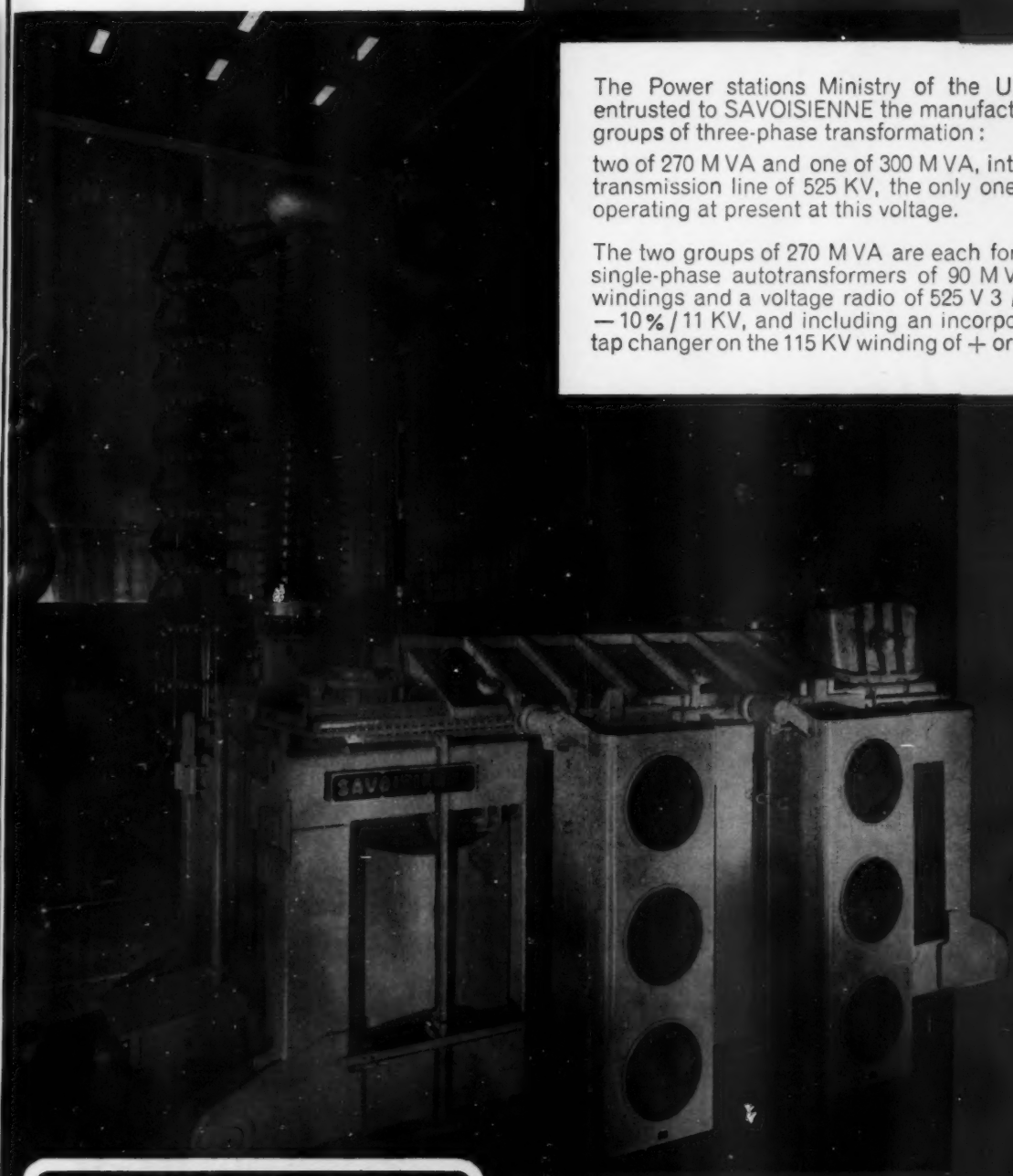
Delle

25 CHEMIN DE CYPRIAN VILLEURBANNE (RHONE)

OF THE "COMPAGNIE GEN

GE TRANSMISSION LINE

525 KV



The Power stations Ministry of the U. S. S. R. has entrusted to SAVOISIENNE the manufacturing of three groups of three-phase transformation :

two of 270 M VA and one of 300 M VA, intended for the transmission line of 525 KV, the only one in the world operating at present at this voltage.

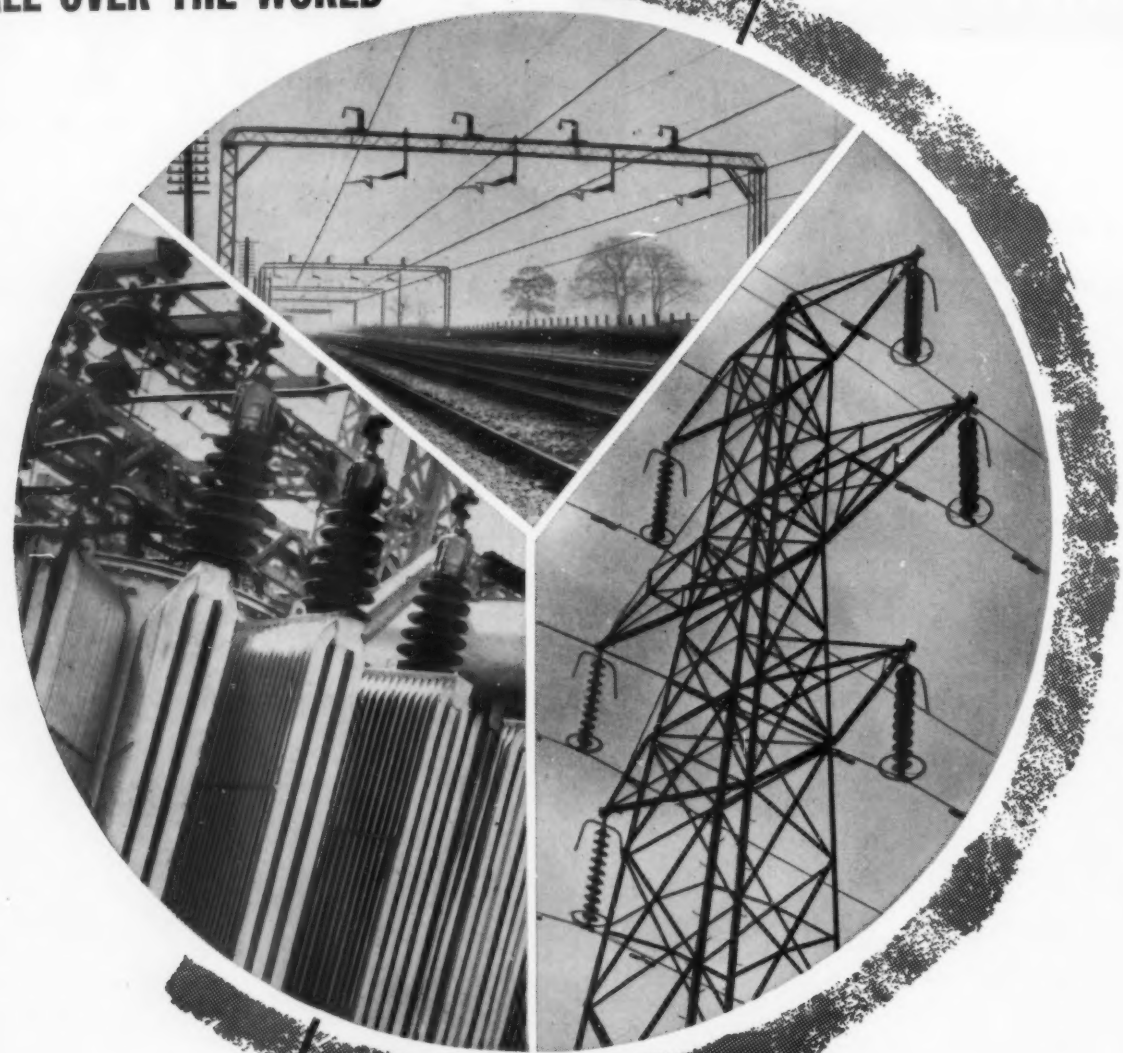
The two groups of 270 M VA are each formed by three single-phase autotransformers of 90 M VA with three windings and a voltage radio of 525 V 3 / 115 V 3 + or — 10 % / 11 KV, and including an incorporated on-load tap changer on the 115 KV winding of + or — 10 % steps.

SAVOISIENNE

AIX-LES-BAINS (Savoie)

NIE GENERALE D'ELECTRICITE"

ALL OVER THE WORLD



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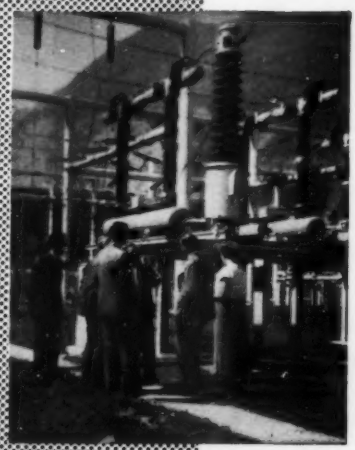
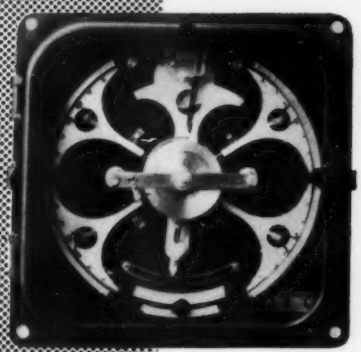
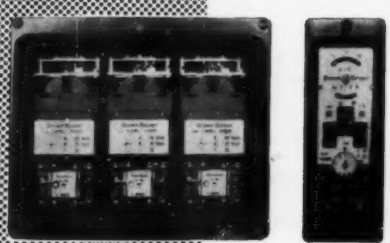


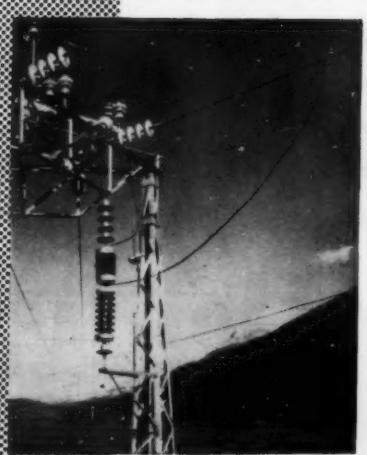
Brown Boveri air-blast circuit-breakers are built from proved, standard components for voltages up to 400 kV and breaking capacities up to 20000 MVA; they ensure stable system operation and protect your installations, machines and apparatus



Brown Boveri quick-acting regulators for the regulation of a.c. and d.c. voltage, current, power, frequency and pressure, require little space and power, no upkeep, only one single setting, and function rapidly and reliably



Brown Boveri generator protection equipment detects widely differing types of faults without risk of undesired tripping and safeguards your generators against disturbances of all kinds



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Brown Boveri telephony and remote supervisory control facilitates supervision and control of your stations. It can be readily adapted to the specified conditions and is economical and ready for service at any time

Our specialists will be glad to advise you

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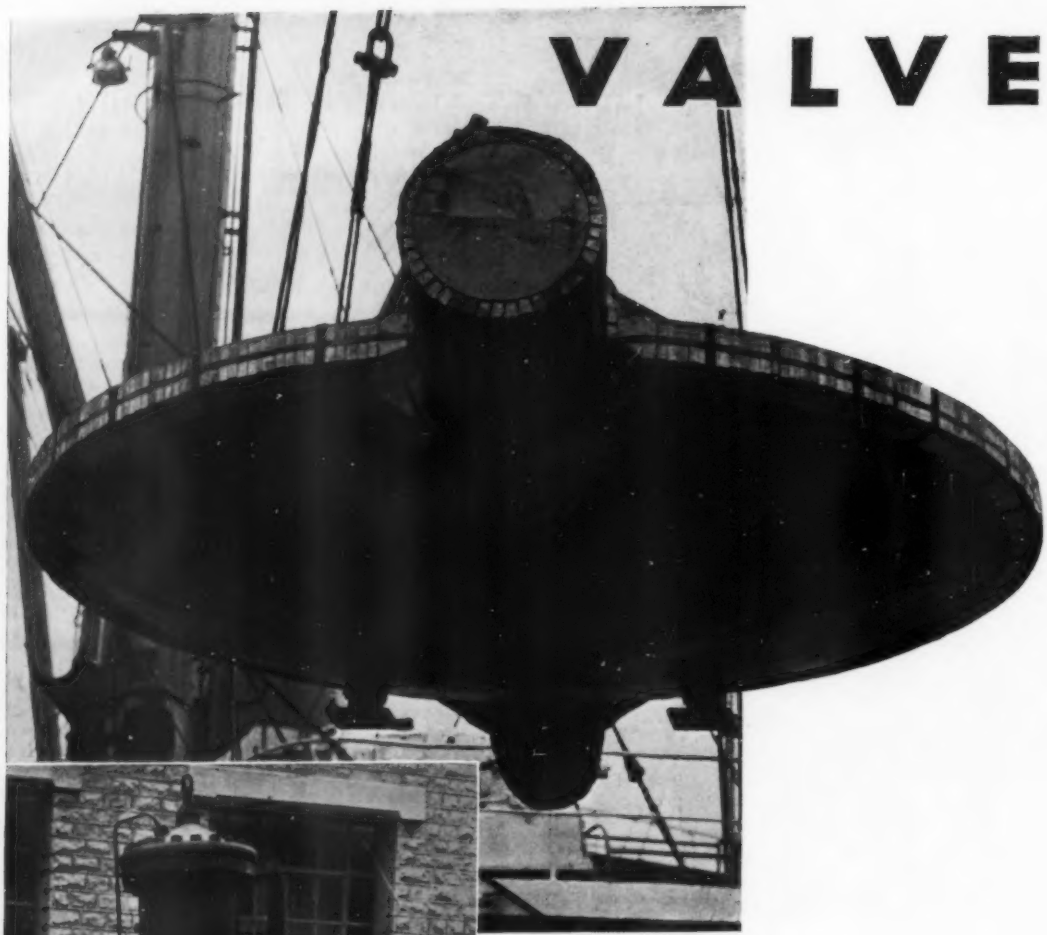
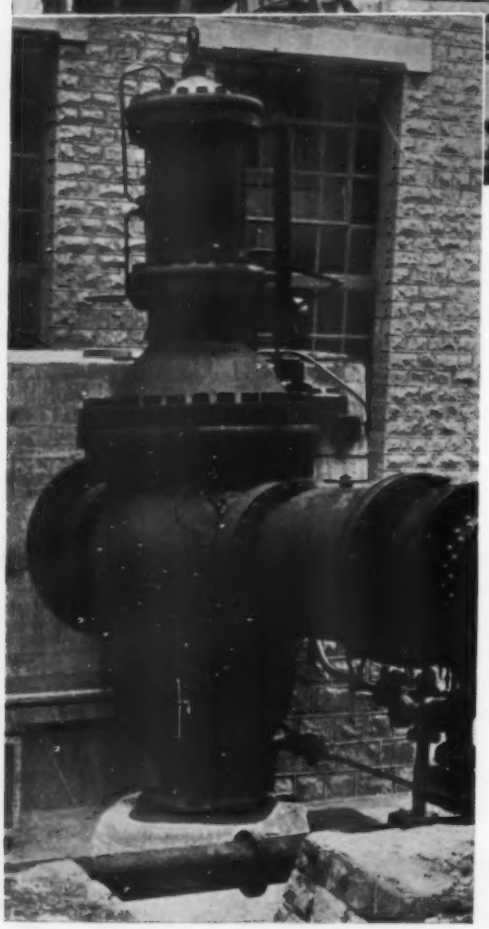
VALVES





for Turbine Intakes

Butterfly and Sluice are two types from the extensive Glenfield valve range that have been widely applied for isolation and other purposes at turbine intakes.

Illustrated is the massive door of one of a number of 14 ft 6 in dia. butterfly valves ordered by Boving & Co. Ltd., London, for the Big Eildon Irrigation and Power Project, Victoria, Australia; and one of several 26 in dia. High-pressure follower-ring sluice valves at Pykara Power Station, India.

Glenfield

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THE FIRST BELLOWS FLOW METER WITH DIRECT FLOW INDICATOR

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Please send me a copy of Publication 1112 giving specification of the AEI/Barton flow meter range.

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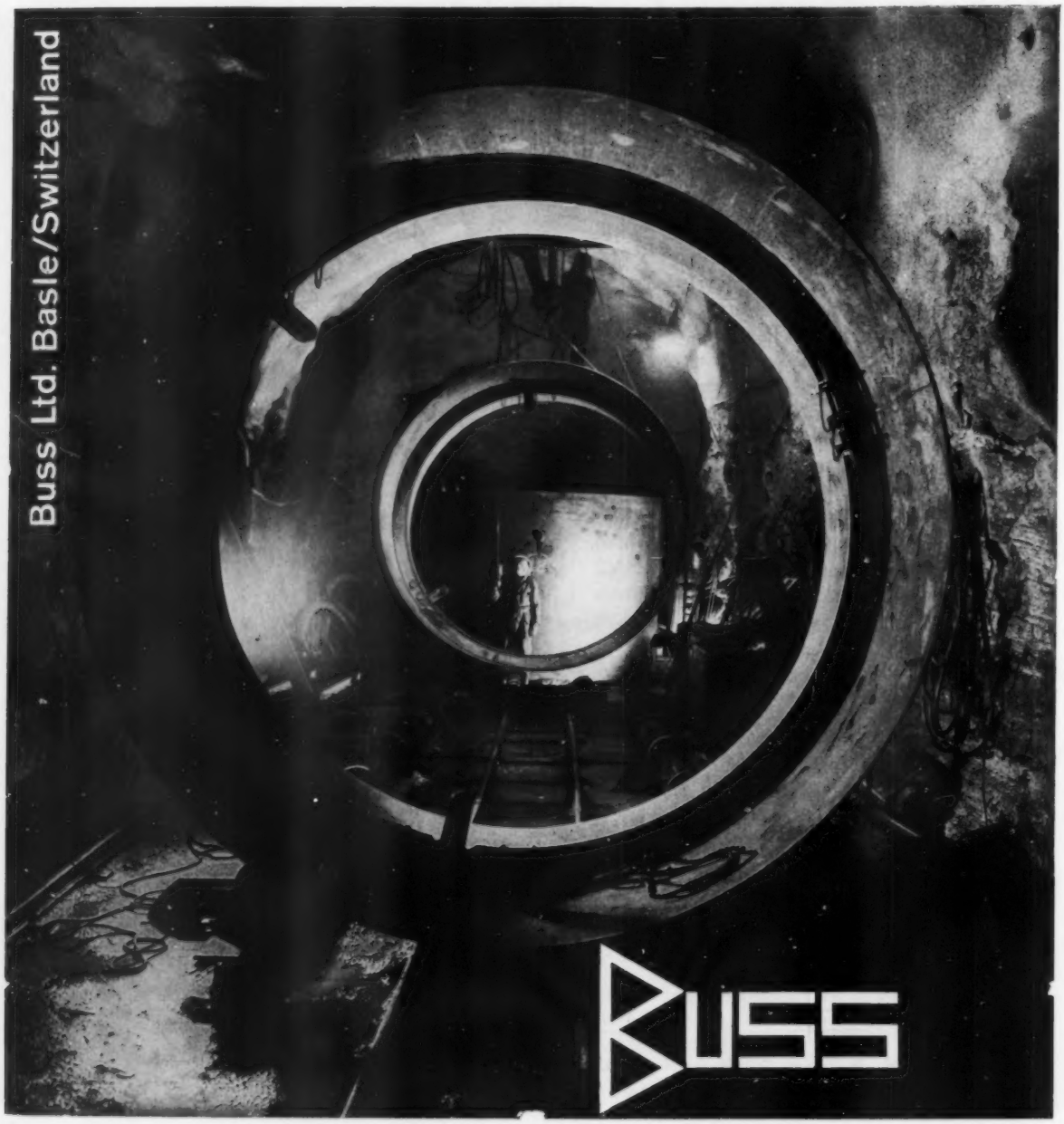
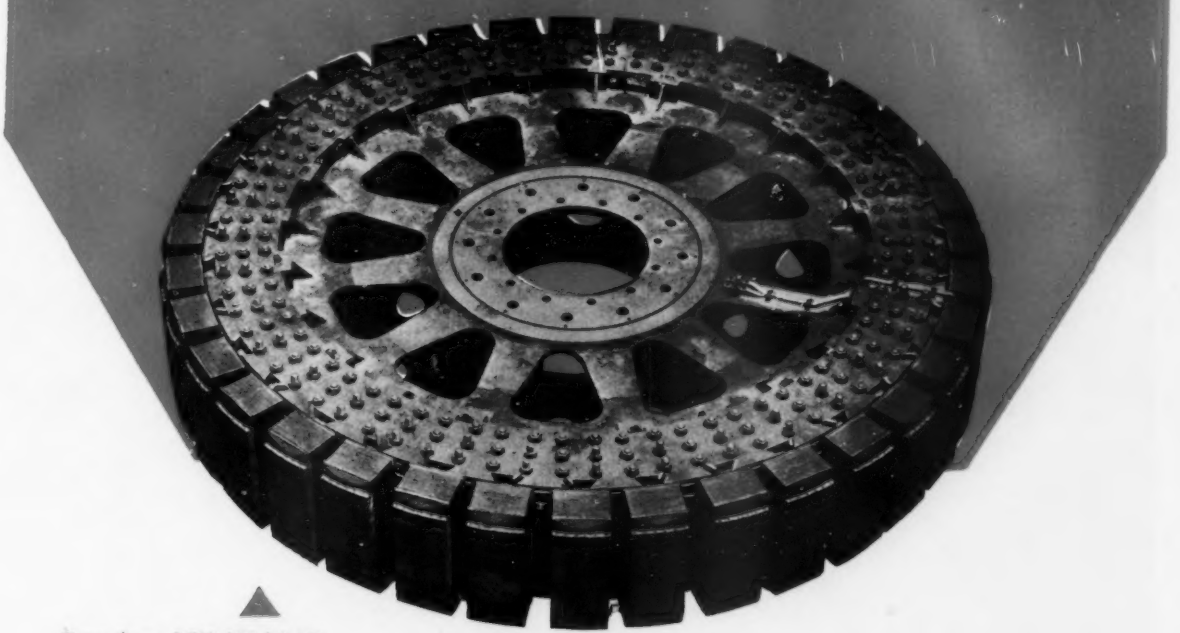
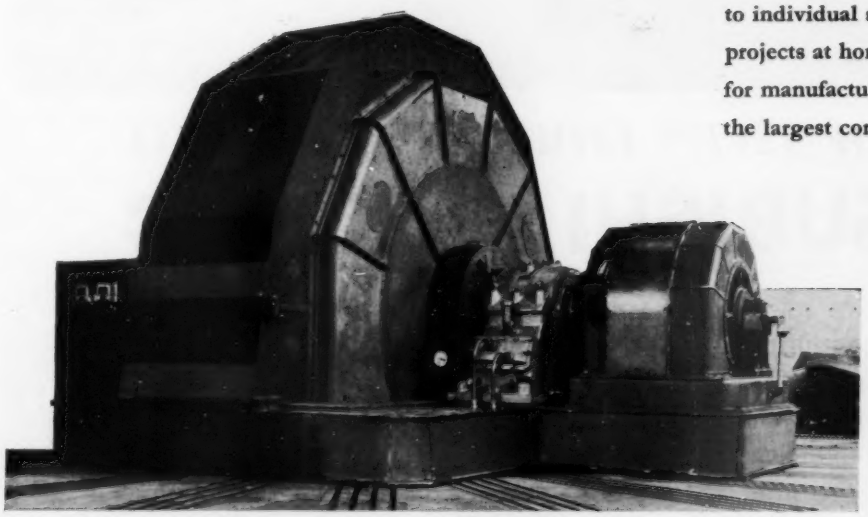


Hydro-Electric Generators



Rotor for a 3,500 kW 3.3 kV 167 r.p.m. vertical generator for the Lairg power station of the North of Scotland Hydro-Electric Board.

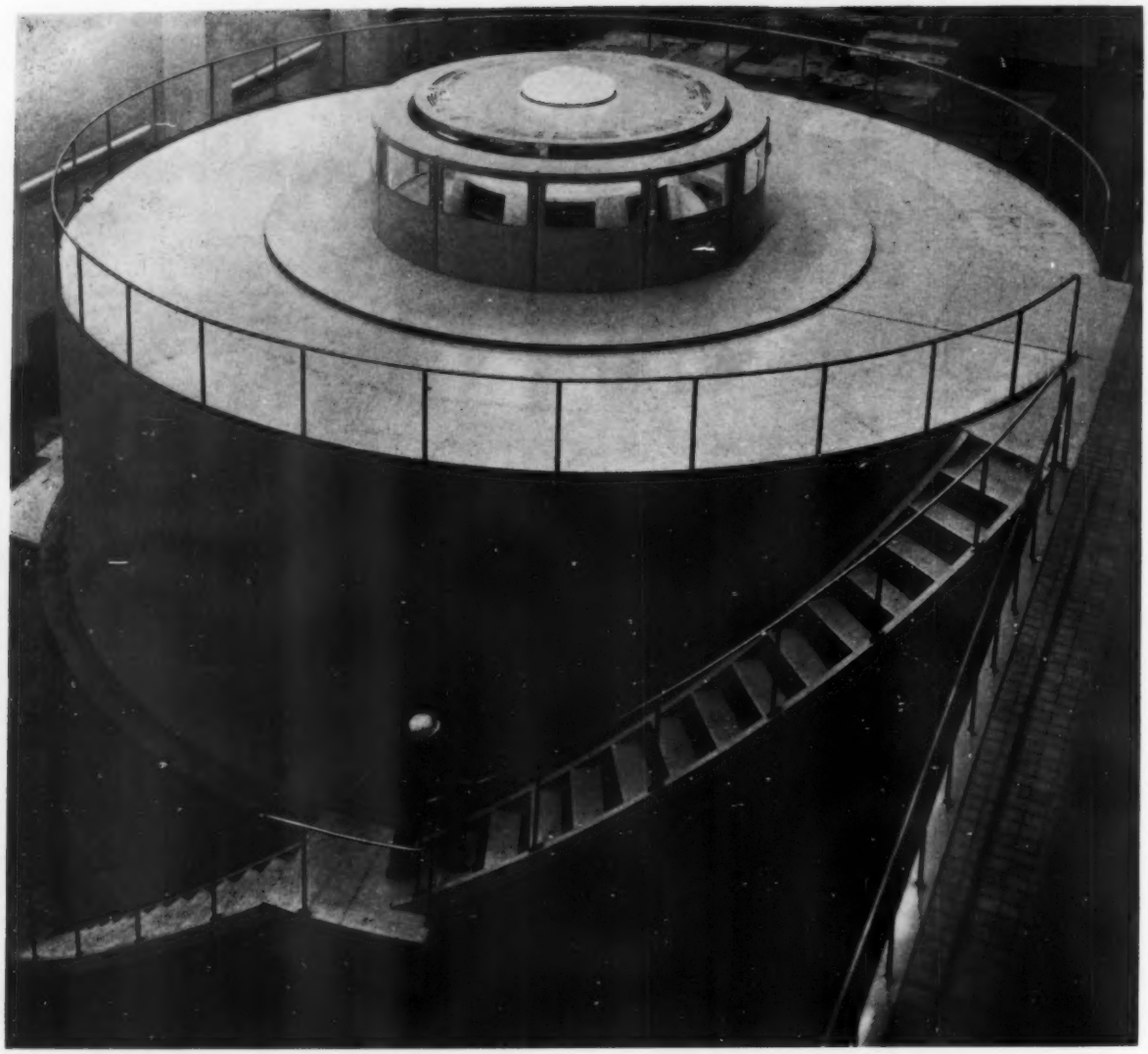
Bruce Peebles build generators, large or small, horizontal or vertical, designed to individual specifications, for hydro-electric projects at home and abroad. Ample resources for manufacture and testing enable the largest contracts to be undertaken.



One of two 12 MW 11 kV 375 r.p.m. horizontal generators for the Shin power station of the North of Scotland Hydro-Electric Board erected for test.

BRUCE PEEBLES & Co Limited ENGINEERS EDINBURGH

105,000 kVA Water-Wheel Generators



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When you think of giant generators, you rarely think of their vital part in making this world a more comfortable place to live in. Yet Mitsubishi Electric's great generators and transformers, plus many large and small home appliances all do just that.....every day in countless ways. Backed by a long history of outstanding achievements, distinguished by the famous Mitsubishi Brand. Do think about it the next time you see the THREE DIAMONDS on an electric appliance.

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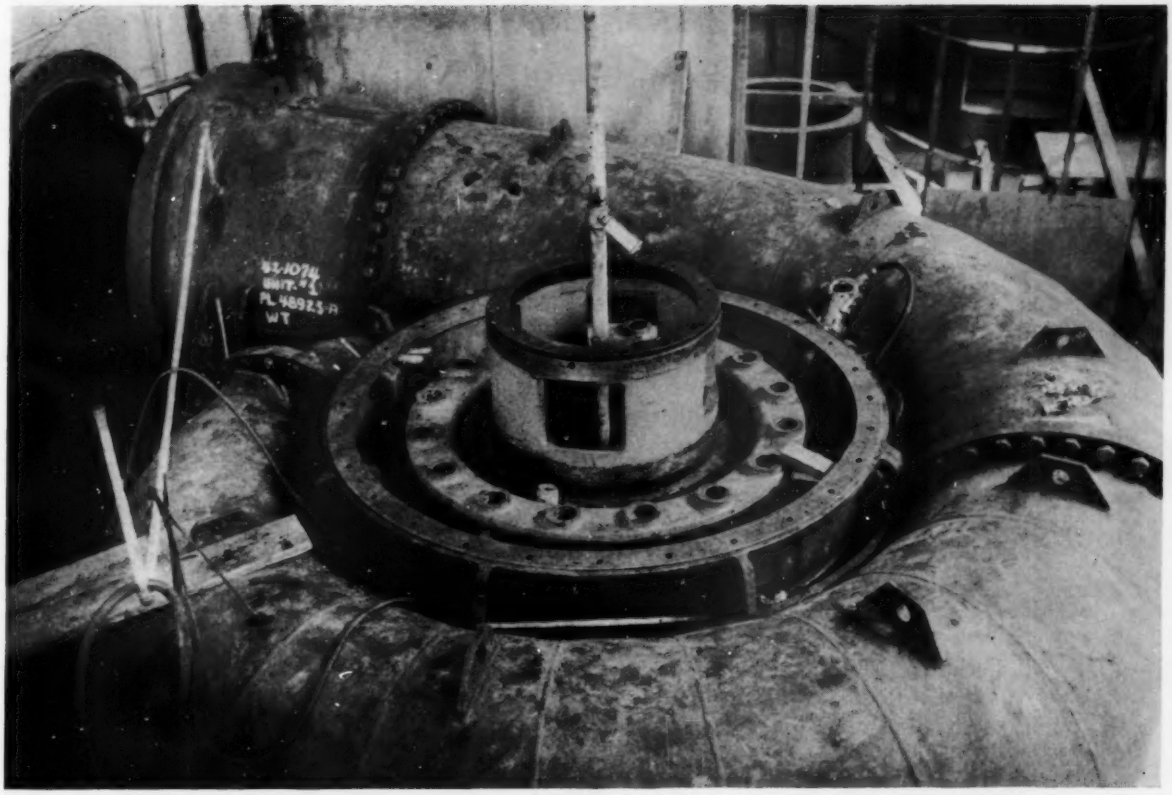

2 Leffel Turbines for Deer Creek

Leffel turbines drive the two generators in the Deer Creek power plant of The Bureau of Reclamation's Provo River Project, 35 miles south of Salt Lake City, Utah. These turbines are of the vertical shaft type, with Francis runners and steel plate spiral cases. Each turbine, rated at 3500 h.p. when operating at 360 r.p.m. under an effective net head of 120 feet, drives a 2750 KVA generator. The photo above shows the spiral casing for one of the Deer Creek turbines during construction of the power plant.

The Deer Creek installation is just one of hundreds throughout the world which utilize Leffel turbines in the efficient and economical development of power from water. Leffel produces turbines of all types and sizes for operating heads from 3 to 1000 feet. And the accumulated experience of nearly a century of specialization in more efficient hydraulic power goes into the design and construction of every Leffel unit.

This experience, available without obligation, can be of real help to you if you're planning a new project or considering the expansion or rehabilitation of existing facilities. For more information on how Leffel can help you get your hydro project off on the right foot, just drop us a line with the details or clip and mail the coupon below.

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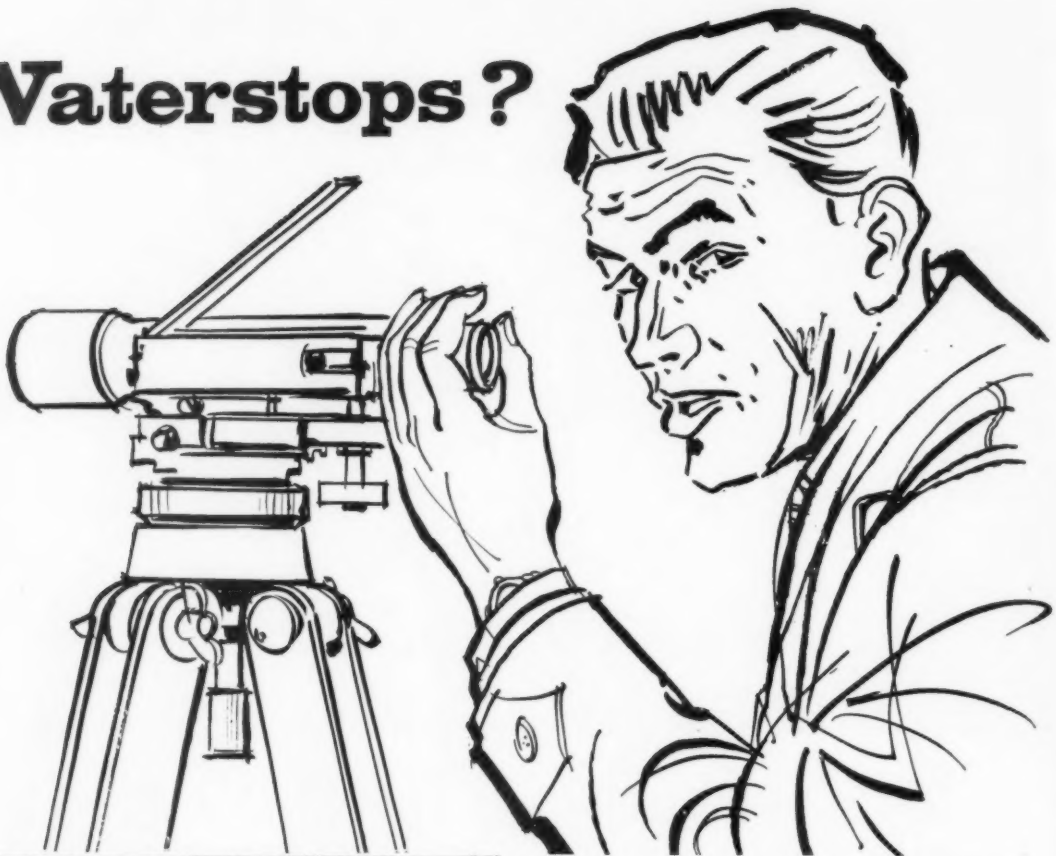
Waterstops?



The New Underpass, Hook Road constructed by William Old Limited for the Surrey County Council

Expandite Limited produce a complete range of efficient Rubber and PVC Waterstops for every type of joint. Made in various designs and lengths, they are accepted as being the most effective and economical method of ensuring watertight structures.

Expandite Waterstops are specified by architects the world over because, unlike metal waterbars, they are not subject to corrosion and will not fracture with movement.

Not content to rest on their laurels, Expandite are constantly introducing new developments. The HYDROFOIL (PVC) revolutionary design combats all seepage, and is suitable for walls, floors, reservoirs, sewage works, ponds, etc. where limited movement may occur.

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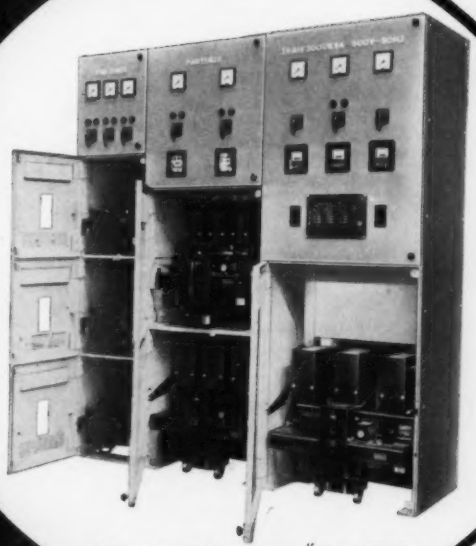

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HITACHI

Another Big Hydraulic Turbine and Generator by Hitachi

Hitachi has recently completed two 137,500 kW/125,000 kVA hydraulic turbines and generators for the Miboro Power Station in Central Japan. The turbine is of the vertical-shaft Francis type, and specified for a speed of 225 r.p.m., a maximum effective head of 200m and 76.6 cu.m/sec. water flow, making it one of the largest units of its kind in the world. Its runner has a maximum diameter of 3.7m and the main shaft a diameter of 95cm. The spiral casing, which was constructed in 13 sections to facilitate transportation to the site, has an inlet diameter of 3.35m and an outer diameter of 11.2m.

The generator presents a high-torsoed appearance, having been so designed in consideration of the comparatively high speed. Since the generator was designed for a rated voltage of 16,500 volts and. in this respect, represents the first such attempt in Japan, particular care was taken in the corona-shielding and impulse resistance of the stator winding. The generator is rated at 60 cycles, 225 r.p.m. and 0.9 power factor, but is also capable of operating at 50 cycles, 187.5 r.p.m. and 1.0 power factor.

Hitachi, Ltd.
Tokyo Japan
Cable Address: "HITACHY" TOKYO

66,000lbs.

(30,000 kg) EXTRA HEAVY DUTY TYPE SUSPENSION INSULATOR

12-5/8″ (320 mm) Dia. and 7-11/16″ (195 mm) Spacing
NGK Cat. No. CA-590ND ; IEC recommended 24 mm ball & socket coupling

The general trend of modern power transmission is an increase in the transmission voltage to 300 kV, 400 kV, . . . , etc. Preparing for these EHV power transmission, NGK has already completed "EXTRA HEAVY DUTY TYPE Suspension Insulator" with minimum guaranteed electro-mechanical strength of 66,000 lbs.(30,000 kg). Besides this, NGK supplies 46,000 lbs. (21,000 kg) Suspension Insulators with 11″ dia. x 6-11/16″ spacing, and IEC recommended 20mm ball and socket coupling dimensions.

This extra-high strength can only be achieved by constant improvement in design, use of high quality materials and progressively advanced manufacturing techniques. The most important part of suspension insulator is the pin head, the shape of which controls mechanical strength of insulator. Through practical experiences and continuous researches over 40 years, NGK has proven that the most suitable shape for the pin head is the convex head (gradual carvature). At present, this type pin is NGK standard. The convex shape distributes the mechanical stress most evenly. The mechanical load applied to the pin is transmitted from the convex head of the pin through porcelain and cement, and the stress is evenly distributed against the inside of the cap. Therefore, porcelain, cement and inner shape of the cap are also important parts. Coupled with the convex head of the pin, these extra-high strength insulators have been completed by improved inner shape of the cap, the use of specially prepared high quality cement produced through the joint research of NGK and a specific cement manufacturer, and the use of NGK high strength porcelain from superior raw materials available in Japan.

You get so much more out of NGK Insulators

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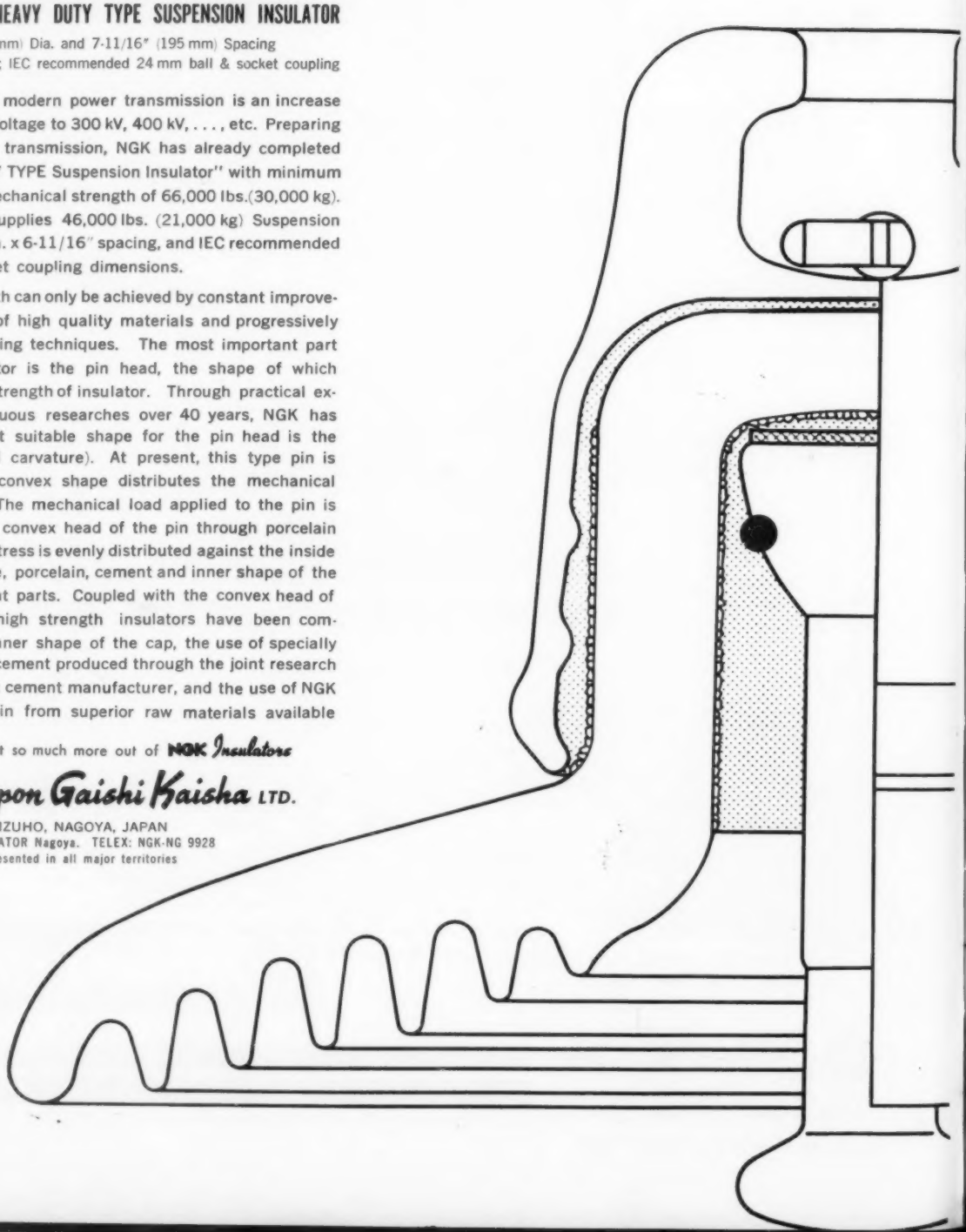

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The highest head in the world

At the Reisseck Power Station in Austria three units work under this fantastic head. All of them are equipped with Pelton runners in 13% Chromium Steel cast at George Fischer's steel foundry and delivered to Charmilles Engineering Works Limited, Geneva.

The successful production of intricate steel castings, such as the Reisseck impulse runner shown here, is the result of our extensive research, wide experience and technical skill in steel founding.

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the steel foundry for water turbine runners

VÖEST

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Hydraulic Turbines, Spherical and Butterfly Valves

Licensed by Baldwin-Lima-Hamilton Corp.
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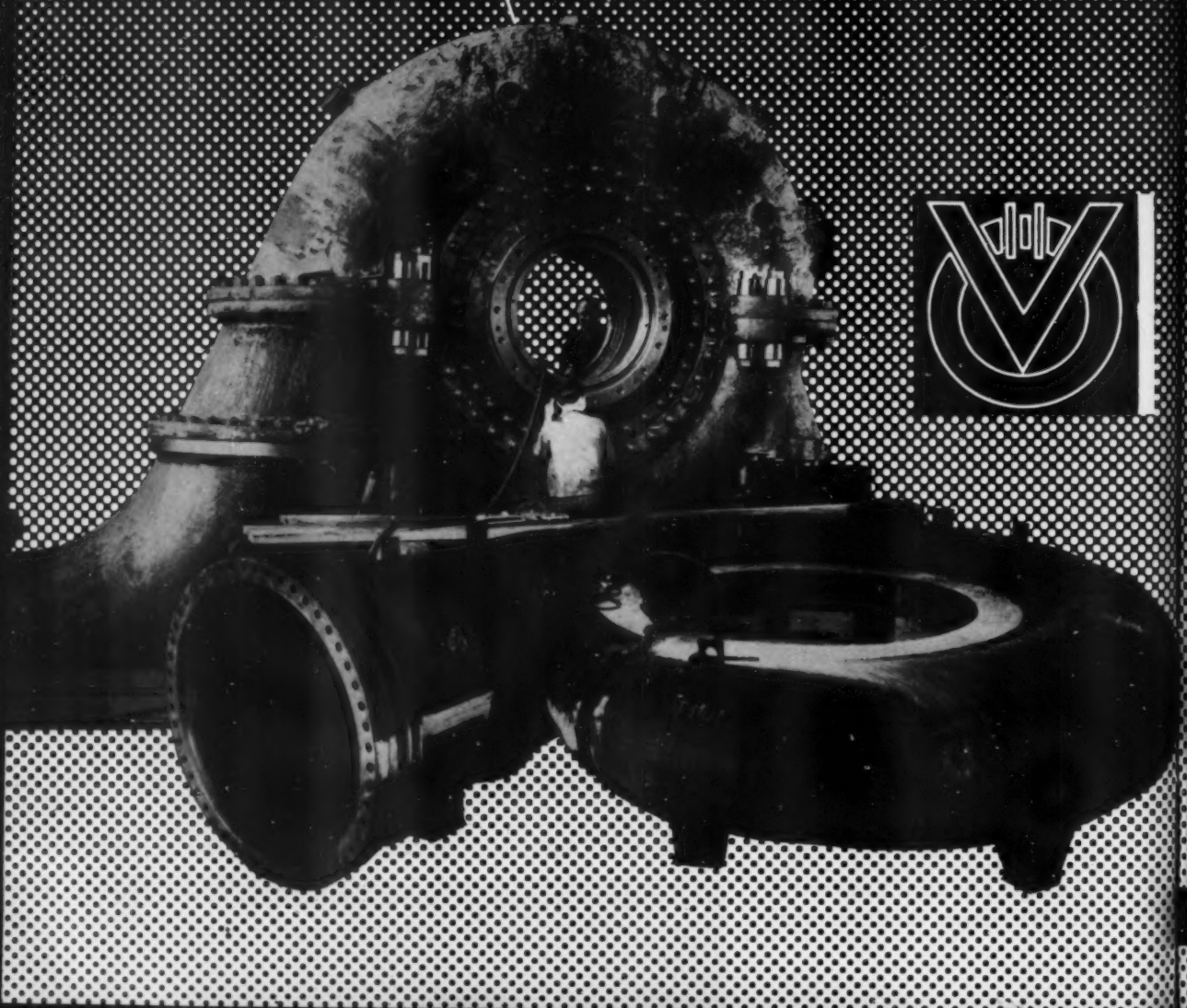

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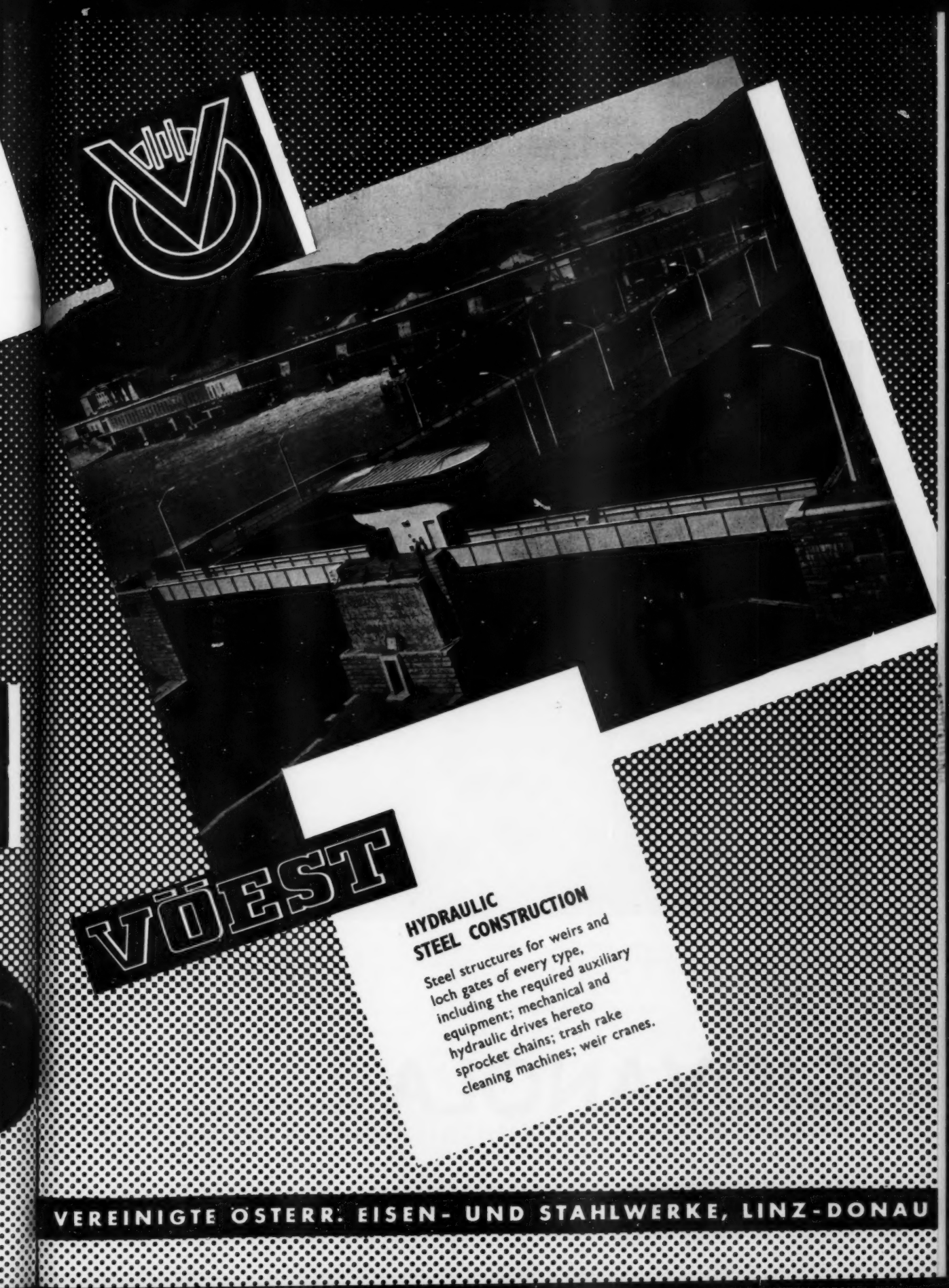

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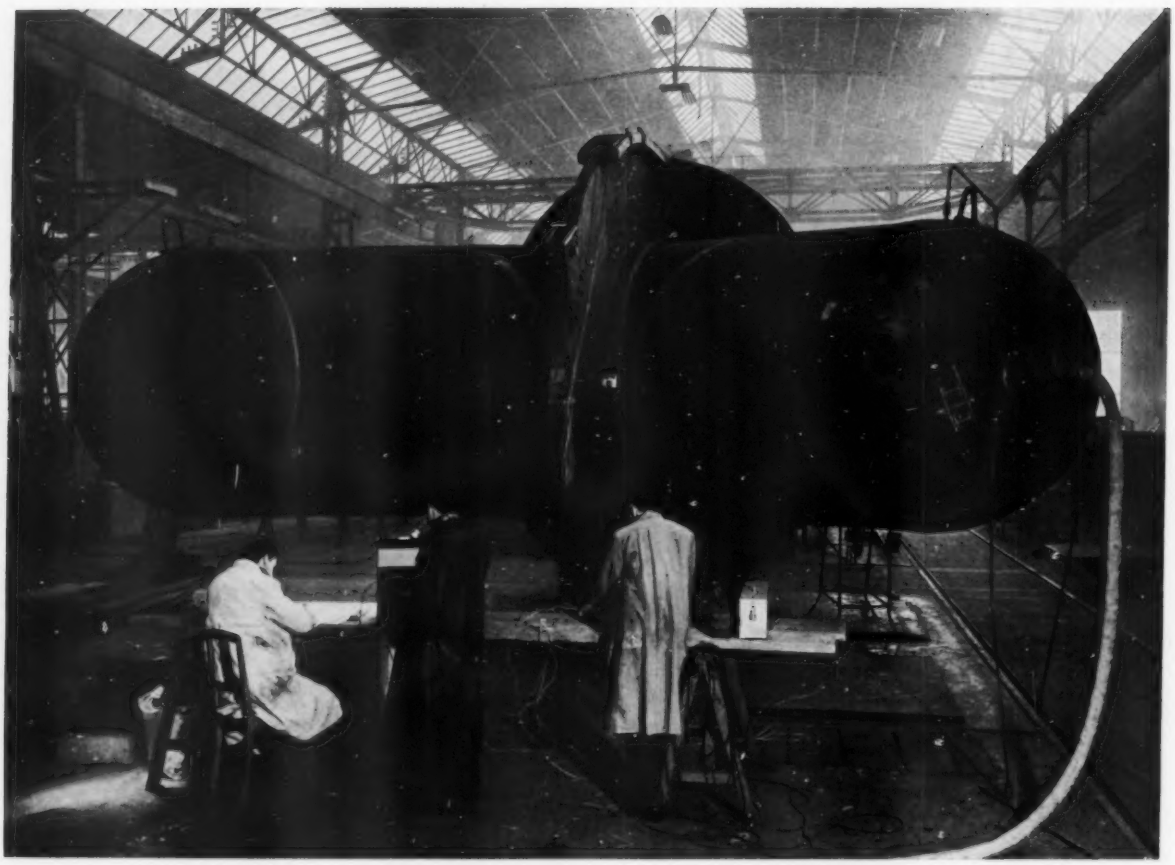
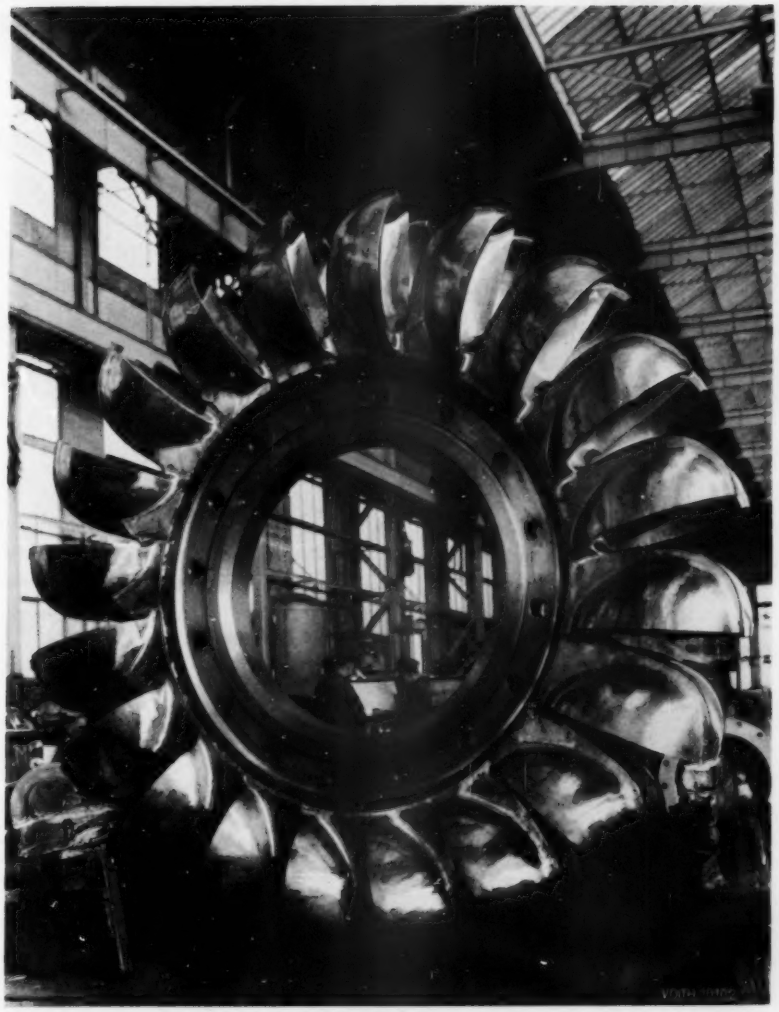
Penstocks, pressure shaft linings,
Substation steel structures
Gantry and overhead travelling cranes
Pylons, water gates



Pressure test and Electric Strain Measuring carried out on the Manifold of the Koyna Power Station (Maharashtra State, India). Test pressure 1420 psi. Diameters 8′ 6″ / 2 x 6′. Thickness 1″ 27/32 and 1″ 37/64. Weight 40.5 tons.

GIOVANOLA Monthey - Switzerland

VOITH



Cubatão
Power Station
Brazil

95,700 hp
2,230 ft head

These data apply to a double-runner overhung double-jet type horizontal-shaft Voith impulse turbine, three of which are operating in the Cubatão Hydro-Electric Power Station in Brazil. The workshop photo shows a spare wheel which we supplied recently for this installation. – Some large vertical-shaft impulse turbines supplied by Voith: two 4-jet impulse turbines for the Lünersee Pumped-Storage Plant (Austria), each developing 62,800 hp at abt. 3,050 ft head; two 100,000-hp 4-jet impulse turbine runners for the Wadagawa Power Station (Japan); two 136,000-hp 6-jet impulse turbines for the Kurobegawa No. 4 Power Station (Japan), in successful operation since January 1961. – Write for complimentary copies of our pamphlets!

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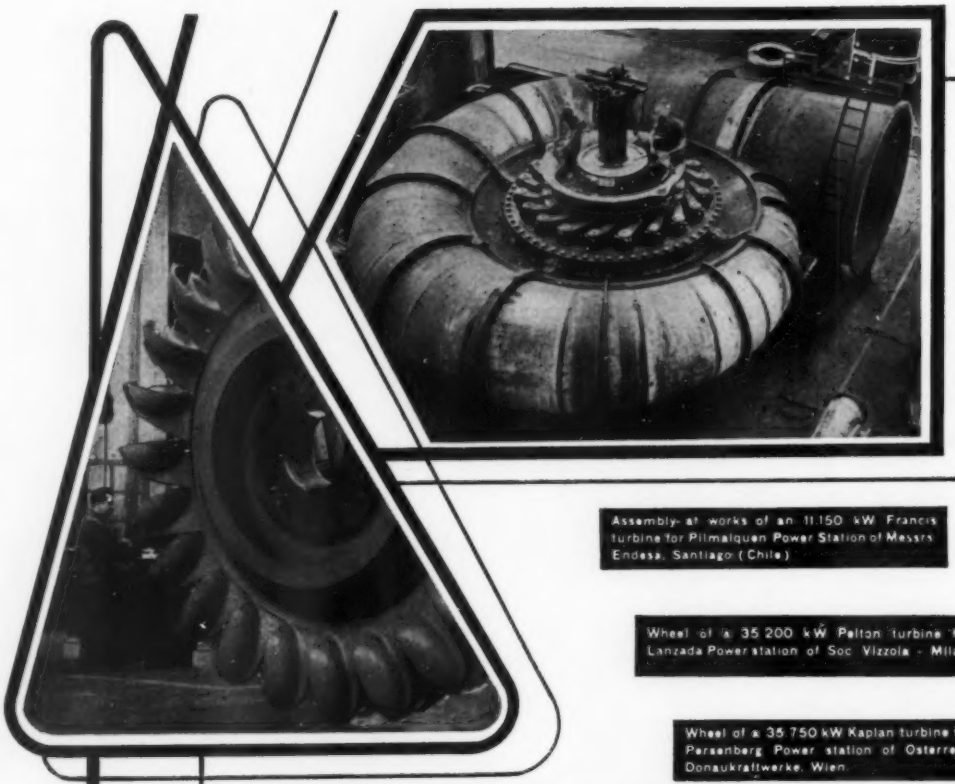
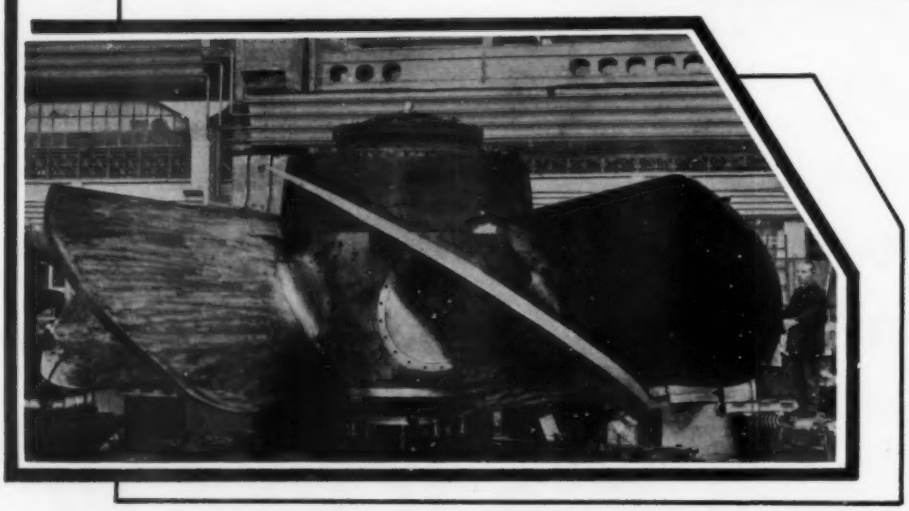


Assembly at works of an 11.150 kW Francis turbine for Pilmalquen Power Station of Messrs Endesa, Santiago (Chile)

Wheel of a 35.200 kW Pelton turbine for Lanzada Power station of Soc Vizzola - Milan.

Wheel of a 35.750 kW Kaplan turbine for Ybbs Persenberg Power station of Osterreichische Donaukraftwerke, Wien.



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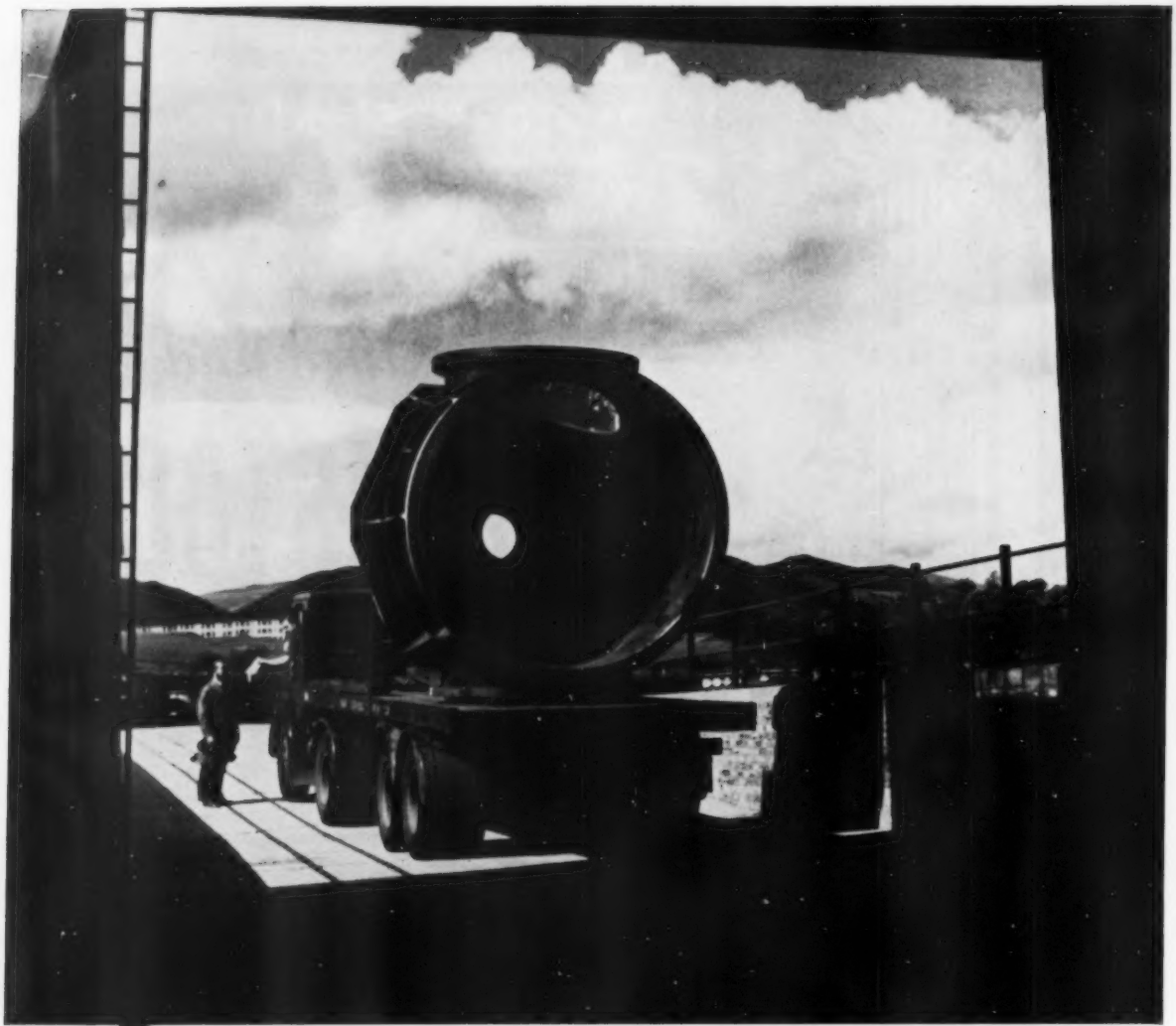

Part of a large Rotovalve—for installation in one of Britain's latest Wind Tunnels—leaving our Alloa works

Here, there and everywhere throughout the world Harland have an unequalled reputation for the design and construction of modern equipment. Specialisation in hydraulic, electrical and control engineering is the basis of Harland's interest in the application of pumps, motors and rotovalves for the most complicated and complex projects.

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WATER POWER

A technical journal devoted to the study of all aspects of hydro-electric development

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WATER POWER

A technical journal devoted to the study of all aspects of hydro-electric development

Harnessing Smaller Power Sources

IN most countries where water power is the predominant method of providing for the country's electrical needs, work is taking place on many small schemes to increase the flow into reservoirs and to build up storage capacity. Some of these schemes are indeed very small; but cumulatively the amount of new water that is being brought to the turbines of the larger schemes in this way must be of immense proportions.

Probably too little use is being made as yet of these additional water flows for power generation. In many cases there has appeared to be an obvious reason. It is feasible from the hydraulic point of view to add to a catchment area a stream running down another valley—perhaps by boring a short, small tunnel—but it may not have been considered economically feasible to install a 100-kW or even a 1,000-kW generator and the associated transmission line. Many manufacturers have available extremely economical forms of water turbine, down to the smallest sizes, but in general the conventional electrical equipment needed has been found to be too costly.

Of recent years, however, there has been a renewal of interest in the induction generator for small units. In Scotland, for example, a considerable number of these sets are now in service, including a 5,000-kW plant at Sron Mor, and it has been found worth while to install units down to 30-kW. In other countries as well, these small units—together with the bulb-type sets developed in France, Switzerland, Sweden, Finland, and Germany—have shown the way towards utilising a considerable store of untapped water power.

The induction generator makes for an extremely simple type of hydro-electric station. It cannot be used, of course, as the sole source of supply to a public network, since it needs magnetising current, and the turbine to which it is coupled is not usually fitted with a speed governor. But if these limitations can be accepted—and with careful choice of voltage the transmission lines can be made to the cheapest possible standard, since they are not intended as the sole means of supply—then there is a strong case for installing many more generating sets of this type. It has been found in Scotland that a 50-kW machine can generate as many as half-a-million units each year; if such a set were situated in an auxiliary intake connected to a main reservoir, the civil-engineering costs associated with the generating unit alone need be very small, since the main works have been carried out in any case for the purpose of augmenting the water supply to the main reservoir. These sets may therefore provide very-low-cost units, and the ruggedness associated with simple induction-generator machines will conduce to very low maintenance costs. Furthermore, in these days of ever-increasing flexibility of automatic control over the transmission lines or through radio links, such stations can be brought into commission or taken out of service with the greatest possible ease from a central control point, or may be operated entirely automatically, depending on various factors such as available head, time of the year, or any other variable.

Another case in which consideration might well be given to a much wider utilisation of simple induction-generator machines is in connection with the compensation water that has to be provided for irrigation, fishing or navigation when constructing very large schemes. It offers interesting and rewarding prospects to the civil engineer to consider how many of the existing compensation-water arrangements could be modified to take even very small generating units. The civil-engineering work involved in cases of this description is likely to be small, but it nevertheless calls for a high degree of engineering skill so as to save every penny of avoidable cost.

As a final point, these simple auxiliary sets are often available at peak-load periods, when each unit they can produce is particularly precious. This is but another instance of the value of these machines in making a humble but most welcome contribution to the needs of the system.

Scottish Power Inquiry

MR. J. S. MACLAY, Secretary of State for Scotland, has appointed a departmental committee to review the arrangements for generating and distributing electricity in Scotland. The committee is to consist of Mr. C. H. Mackenzie (chairman), Sir Josiah Eccles, Prof. A. T. Peacock, Mr. E. W. Craig, Mr. J. Craig, Mr. J. S. Grant and Mr. J. A. Keyden. Its terms of reference will be wide, but its primary purpose is obviously to consider whether the North of Scotland Hydro-Electric Board's policy of continuing to develop the country's water-power resources is the correct one.

Opinion in the Highlands appears strongly to support the Board and to resent the attacks that have been made on it. In 1957 a Select Committee on Nationalised Industries reported that the Board had "impressively justified the faith of its progenitors," and it is felt that a further investigation is unnecessary.

It is our view that many, if not most, of the criticisms of the Board have been misguided and that an impartial inquiry can hardly fail to vindicate the Board's past record and future policy. Some advantage can thus be seen in the appointment of a departmental committee designed to settle the questions at issue beyond dispute.

Unfortunately it has been decided to hold in abeyance a decision on the Glen Nevis scheme until the committee has reported, and a delay of nine months is expected.

Malayan Hydro-Electric Contract Awarded

A CONTRACT for the supply and erection of mechanical and electrical plant for the hydro-electric power station at Habu, Malaya, has been awarded to Humphreys & Glasgow Limited, of London. The new station is part of a general development scheme in the Cameron Highlands in Northern Malaya. The contract has been placed by the Central Electricity Board of the Federation of Malaya, whose consulting engineers for this project are the London firm of Messrs. Preece, Cardew & Rider.

The plant consists of two 2,750-kW generating sets together with auxiliary equipment for the power station. The turbines will be supplied by Gilbert, Gilkes & Gordon Limited, of Kendal, England, and the alternators by Tecnomasio Italiano Brown Boveri, of Italy. Work has already started on the plant and is expected to be complete in just over two years time.

Turbines for Infiernillo

IN our September 1960 issue we reported that the Mexican Government had negotiated a loan of nearly $72 million from a French banking consortium, Banque Nationale pour le Commerce et l'Industrie, for the construction of the Infiernillo hydro-electric development on the Balsac River. The dam will be of the earthfill type and will be 140 m high and 600 m thick at the base.

The Comisión Federal de Electricidad has now placed an order for four turbines and their associated butterfly valves with Ets. Neyrpic, Grenoble. These machines will be of the vertical-shaft Francis type operating under a head of 101 m, and each will be rated at 173 MW (235,000 h.p.). This, we believe, will be the highest normal rated output for a single unit in the western world; indeed, this rating is equalled or exceeded only by those of the Russian machines at Bratsk and at Krasnoyarsk. The runners will have a diameter of 4·8 m and will weigh 60 tons.

It will be remembered that Neyrpic have supplied the turbines for France's most powerful hydro-electric station at Roselend (described in our January and February issues) and for Europe's largest hydro-electric station at Aldeávila in Spain.

Société Hydrotechnique de France Jubilee Congress

LA SOCIÉTÉ HYDROTECHNIQUE DE FRANCE, which was founded at Grenoble in 1912, will celebrate its jubilee next year by holding a week's Congress on Hydraulics. Technical sessions will be held in Paris from June 4 to 6, 1962, and will be followed on June 7 and 8 by a study tour in Lacq.

The inaugural session on June 4 will be devoted to the theme "Present Position and Trends in Hydraulics." It will be addressed by the President of the Society and by the President of the Technical Committee, and three lectures will be given by eminent authorities: "Fifty Years of Hydraulics" by M. Paul Chapouthier, "Hydraulic Machines" by M. Paul Bergeron, and "Hydraulic Engineering" by M. Jean Aubert.

During the remaining sessions six questions will be discussed under the general heading of "Bubbles, Drops, and Surface Tension," as follows: (1) Surface tension; (2) Ebullition and heat transfer; (3) Surface tension in the chemical industry; (4) Cavitation; (5) Some particular types of bubbles and drops—(a) Physics of clouds and fogs, (b) Condensers for steam and refrigerating plants, (c) Pulverisation of liquids, (d) Welding and metallisation by pulverisation, (e) Bubbles in metallurgical baths and in cast products; (6) Surface tension in unsaturated grounds and in materials—(a) Surface tension in soil structure, (b) Surface tension in soil mechanics, (c) Nappes in oil-bearing strata, (d) Air-entrained concrete.

During the study tour visits will be paid to an oilfield, a factory for petroleum-based chemicals, an aluminium works, a thermal-power station, and an underground natural-gas reservoir.

Further details of the Congress and of the regulations applying to the presentation of papers can be obtained from the Society at 199, rue de Grenelle, Paris VII.

Hydro Progress in Quebec

DURING 1960 the Quebec Hydro-Electric Commission placed in service 553 MW of new generating plant, and this brought the peak capacity of the Commission's generating stations up to 3,292 MW. The new additions consisted of five units of 55 MW each at Beauharnois No. 3 plant, two units of 121 MW each at Bersimis II, and six gas turbines, each of 6 MW, at Les Boules generating station on the Gaspé Peninsular. The 517 MW of hydro-electric plant added by the Commission represents 40% of all new plant installed in Canada in 1960.

Despite the considerable increase in capacity during the past few years, further expansion has become necessary and is at present proceeding at the Carillon and Beauharnois stations. This will add a further 740 MW to the metropolitan system. Furthermore, additional installations totalling 4,427 MW are

either under active planning or in the preliminary stages of construction. These plans include the final unit for the Beauharnois No. 3 development; an additional 12 MW unit at Rapid II; 675 MW at Lachine; and exploitation of the Manicougan and Outardes Rivers. Completion of these projects will bring the peak-load capacity of the Commission's generating stations to a total of 8,459 MW.

New York State Power Authority

ACCORDING to its latest Annual Report, dating to the end of February, 1961, the Power Authority of the State of New York regards 1960 as the most important year in the history of the Authority. During that year the construction of the American side of the St. Lawrence Seaway was certified as complete, and progress on the construction of the Niagara Falls project was such that the three-year-old promise to deliver first power on February 10, 1961, was kept. The event was recorded in our March issue.

Power generation at St. Lawrence totalled 6,311 GWh during the year, a decrease of 700 GWh on the previous year due primarily to below-average flow, but the project maintained a satisfactory record in meeting its firm-power and financial commitments. In collaboration with Ontario Hydro a major feature of 1960 was a test programme to study the most economic use of St. Lawrence water for power generation. Peaking tests have indicated that fluctuations of up to 30,000 cusecs above and below the daily average releases are generally feasible without adverse effects, and the effects of saving water at week-ends for use during the week are also being investigated.

The first generating set at the Robert Moses Niagara plant was placed on test on January 12, 1961, and the second on February 3. Succeeding units are scheduled for commissioning at five-week intervals, and by the end of 1961 sufficient units will be operating to make the use of the pump-generating plant economical.

A description of the Niagara plant will be published in this journal shortly.

New Contracts Placed for the Awe Project

THE North of Scotland Hydro-Electric Board have placed a contract with the Mitchell Construction Co. Ltd., Peterborough, for the construction of an access road some 4¾ miles long, a tunnel 2¼ miles long, and an underground power station for the Nant section of their Loch Awe scheme. Another contract, for building aqueducts in the Nant section, has also been let to the same company. Work on these contracts has already started, and will increase still further the labour force of about 300 men at present employed on the Awe scheme.

Annual Report for the State of Victoria

THE 41st Annual Report of the State Electricity Commission of Victoria for the year ended June 30, 1960, shows that the total output of the Commission's hydro stations was about 85 million kWh less than the previous year. Some 538 million units were generated, and an additional 55·7 million kWh were supplied from the Snowy Mountains system. A reduction of the quantity of water available is believed to be responsible, as the total output of energy by all the power sources of the Commission's state system rose by nearly 10% to over 6,100 million units.

The main hydro feature mentioned in the Commission's report was the completion of the McKay Creek power station (see WATER POWER, March, 1961). A small unit was also installed at the Cairn Curran reservoir in central Victoria.

Congress on Large Dams

THE Central Committee of the International Commission on Large Dams has issued a list of the papers to be presented to the forthcoming Seventh International Congress to be held in Rome from June 26 to July 1, 1961. The list includes 124 papers under the four Questions: aggregates for large dams, underground work in connection with large dams, concrete dams for wide valleys, and sealing earth and rockfill dams with bitumen and other materials. Judging from the titles of the papers and the names of the authors an exceedingly interesting Congress is assured. Four General Reports on the papers relating to the four Questions will be presented, and particulars of these and of 25 Communications dealing with matters not falling within the scope of the four Questions will be issued later.

Interested readers should apply for copies of the list of papers through their respective National Committees.

Second Dominican Republic Project

STUDIES costing $600,000 for a second Dominican Republic hydro-electric project, which will also provide a water supply for the capital sufficient to meet the needs for the next 50 years, have been contracted to Dominican engineering firms. The work, which will involve the damming of the second largest river in the south, the Nizao, will be thoroughly prepared in the planning stages and European geologists are being consulted.

Submarine-Cable Link Approved

THE New Zealand Minister of Works and Electricity has announced that the New Zealand Government has approved the laying of a submarine cable across Cook Strait to link the North and South Islands. The cable is expected to come into service by 1965. The present estimate of cost is £18,803,000, and tenders are expected to be called for very shortly. The consultants to the Government have recommended the use of a d.c. system at 500 kV, and the proposed route length of the cable is 25½ miles.

Mexico's Electricity-Supply Problems

AS a result of Mexico's increasing need for a rationally developed electricity-supply industry, and, in particular, the country's need to develop its hydro-power resources in an economic fashion, the Government has now completed its nationalisation of the several privately owned systems. The most pressing problems now confronting the Federal Electricity Commission are those of a unified rate structure, the interconnection of the various systems, and the replacement of obsolete plant.

It is vital that the existing systems be expanded to meet the demand, which is growing at a rate of at least 10% per annum, and the annual increase in installed capacity planned by the Government is some

417 MW. The cost of the new developments is likely to be about $500 per kW, including all generation, transmission and distribution costs. Thus a considerable financial investment will be called for over the next few years, and it is hoped that part of this will be met by improving the efficiency of the existing systems.

A major obstacle to the interconnection of the systems in the central, and most important, region of Mexico, is the existence of two operating frequencies, 50 and 60 c.p.s. A decision has to be made on whether to install converter stations or eventually to unify the system frequencies at a substantial capital cost, the funds for which might well be employed on new developments elsewhere in the country.

Ceylonese Contract for Swedish Firms

TWO Swedish contractors, Skånska Cementgjuteriet and Widmark & Platzer, have been awarded a contract for the civil-engineering works for the project known as Stage II B in Ceylon. The works consist of a 6-km long tunnel and a 50-MW power station situated on the Kehelgamu River, about four miles downstream of the Castlereagh dam, and some 60 km east of Colombo. The head to be utilised is about 160 m.

The contract, on which work is to commence immediately, is valued at approximately Kr. 35,000,000, and is expected to take some three years to complete. An additional contract has been awarded to Brown, Boveri & Co. Ltd. for the generating units.

Loan Approved for Uganda

THE World Bank has approved a loan of $8·4 million to Uganda for the extension of the transmission and distribution systems of the Uganda Electricity Board. Most of the electrical energy used in Uganda is generated at the 120-MW station at Owen Falls, but at present only about half the station capacity is being utilised, including a bulk supply of 22 MW that is sold to Kenya. It is now intended to widen the power market by carrying out a development programme over the next few years, which is designed mainly to extend the Board's service area, and so build up the load on the Owen Falls station.

The new extensions will be mainly in the eastern and western parts of the country, and will include connections to existing industrial centres, which at present generate their own supplies. In addition, a small hydro station is to be constructed at Kabale, which cannot be supplied economically by the main transmission system.

Turbine Contract Awarded for Ontario Project

A CONTRACT for two 84,000 h.p. Kaplan turbines has been awarded to the English Electric division of John Inglis Co. Ltd., Toronto, by the Hydro-Electric Power Commission of Ontario. Design work and model testing will be done in the United Kingdom by English Electric's hydro-electric division at Netherton and Rugby. Work will start immediately on the fixed-blade propeller-type units, and manufacturing operations are scheduled to begin late this summer. The turbines will be designed to operate at 90-ft head at 94·7 r.p.m. The turbines, which are to be completed towards the end of 1962, will be installed at Ontario Hydro's Little Long Rapids generating station on the Mattagami River, some 500 miles north of Toronto, Ontario.

The turbines will be similar in design to the 16 already manufactured by the group and now operating at Ontario Hydro's Robert H. Saunders generating station on the St. Lawrence River. The power produced at Little Long Rapids will eventually be fed into Canada's first EHV transmission system, which will serve north-eastern and southern Ontario at 460 kV.

Developments in Kerala

THE Planning Commission of India has sanctioned the expenditure of Rs. 490,000,000 for electricity schemes to be carried out in Kerala during the Third Five-Year Plan. Of this total Rs. 30,000,000 have been allocated for the initial works on the Idikki hydro project, which is to be completed during the period of the Fourth Five-Year Plan at an estimated total cost of Rs. 350,000,000. The Urukuzhi project in Kozhikode district, which has been allocated Rs. 30,000,000, is due to be completed during the period of the Third Five-Year Plan.

The total volume of water available for utilisation in the rivers of Kerala during the rainy season has been estimated as some 2,456,800 million ft³ on average. The present quantity utilised for power generation is about 75,780 million ft³, and existing plans propose the additional utilisation of some 400,000 million ft³.

Correspondence

Flaming Gorge Dam

To the Editor, WATER POWER

In my article in the March issue of WATER POWER on Flaming Gorge Dam I described the drain holes on the downstream side of the grouting gallery in the base of the dam as "reaching down *to* the foundation rock." This should, of course, have been "*into* the foundation rock," a very important difference. Professor Casagrande, in his recent Rankine Lecture in London, has questioned whether grouting in a moderately tightly jointed bedrock is economically justifiable. But he pointed out that the drain holes were essential to the stability of the dam, and that it was very important to carry them down into the impervious strata. The drain holes are usually 150 to 200 ft deep.

IAN B. MACKINTOSH,
Senior Engineer,
Taylor Woodrow (Overseas) Ltd.

Arthur Arnold

It is with deep regret that we record the death of Mr. Arthur Arnold, A.M.I.Mech.E., A.M.I.E.E., M.I.Plant E., F.Inst.F., editor of our associated journal *Power and Works Engineering*. Mr. Arnold, who was 69 and had planned to retire this summer, was the senior editor on the staff of Tothill Press Limited, in respect both of age and of length of service. He had been with the company for 42 years.

Fig. 1. Grosser Mühldorfersee and Kleiner Mühldorfersee in their natural state

The Reisseck-Kreuzeck Development

This important Austrian scheme, which combines natural-storage, pumped-storage and run-of-river elements, is now in operation. It will ultimately have a capacity of 132 MW and will produce an average of 348 GWh per annum

PART ONE

IN the Leading Editorial in our September 1958 issue we commented on the remarkable development in hydro-electric power that has taken place in Austria since the war. Since that time Austria has brought to fruition a number of important schemes in the design and construction of which she has displayed exemplary skill, typical developments being Glockner-Kaprun (WATER POWER, August and September 1954), Ybbs-Persenbeug (WATER POWER, June 1956), and Lünersee (WATER POWER, August and September 1959). The Reisseck-Kreuzeck scheme, which forms the subject of this article, is another development of similar calibre which is now in nearly full commission.

In the editorial article already referred to, we drew attention to the care with which Austria is maintaining a proper balance between storage and run-of-river plants. She is well favoured in this respect, for the Danube represents a vast potential for base-load power, whereas her high mountains afford ample facilities for storage schemes, which may easily be designed to include pumped-storage facilities. Another mattter in which Austria has taken a lead—also mentioned in our previous editorial—is the interchange of power with her neighbours.

Reisseck-Kreuzeck exemplifies all these aspects of Austrian policy. It was conceived to permit a large-scale interchange of power between Austria and Italy, and a contract to this effect was signed in 1951. Also, it comprises two run-of-river sections and a high-level storage section, these sections being linked together by pumped storage. Incidentally, the storage section boasts what is believed to be the highest bead in the world—1,771·3 m.—to be utilised in a single stage.

A summary of the Reisseck-Kreuzeck development was contributed to this journal in February 1954 by Dr. Erwin Königshofer, but for the convenience of our readers we will outline the scheme afresh with the help of Fig. 2.

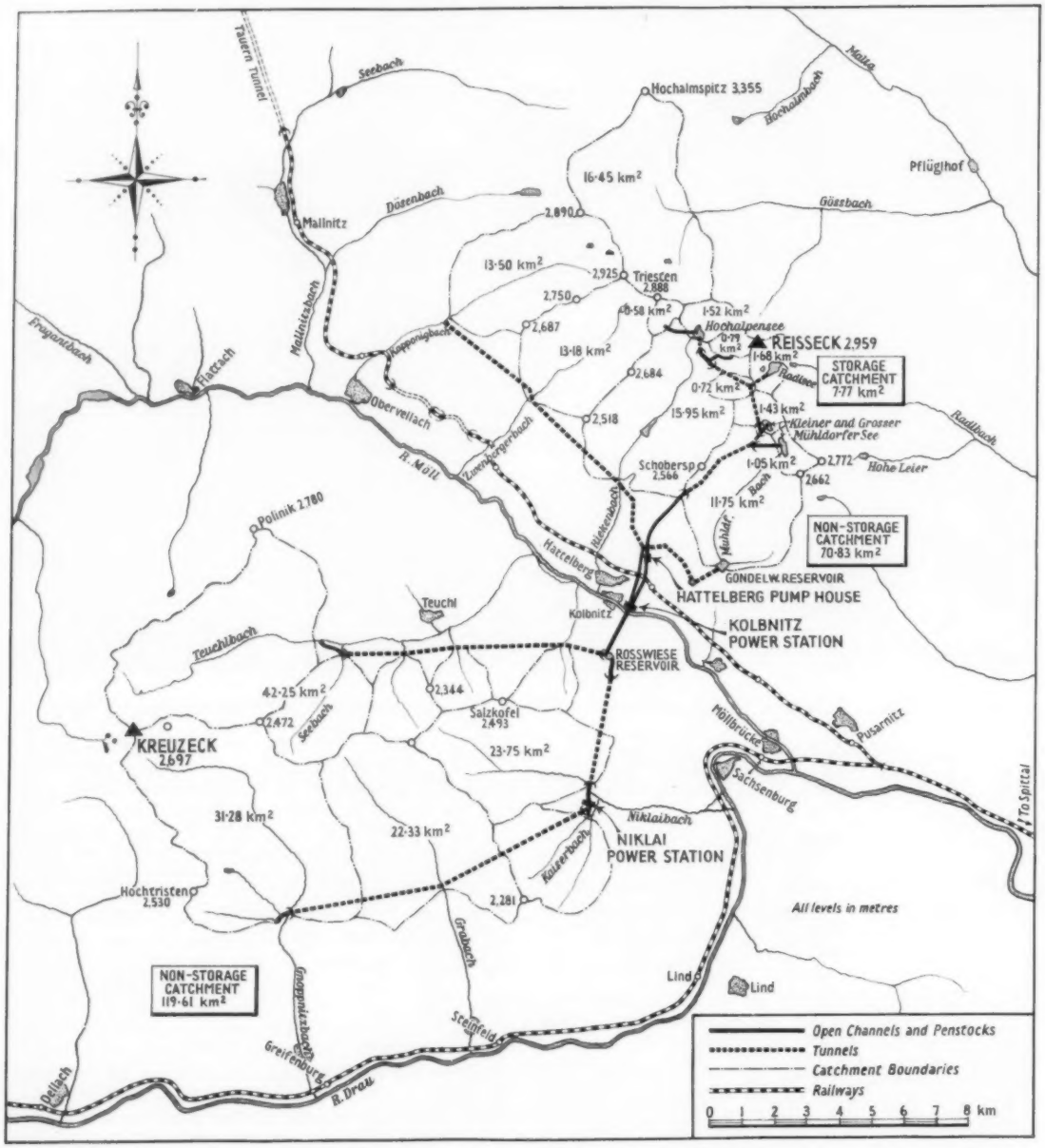


Fig. 2. Map of the Reisseck-Kreuzeck development

The development lies astride the valley of the river Möll, a tributary of the Drau, which flows in a south-easterly direction between the Reisseck massif to the north-east and the Kreuzeck massif to the south-west. These mountains are very high—the Reisseckspitze rises to 2,959 m. and the Kreuzeckspitze to 2,697 m. —and numerous mountain streams flow down their flanks to discharge either into the Möll or direct into the Drau. The key to the storage part of the scheme, however, lies in the fact that on the Reisseck massif there are several small high-level lakes—the Grosser Mühldorfersee, the Kleiner Mühldorfersee, the Radlsee and the Hochalpensee—lying at elevations between 2,284 m. and 2,390 m. and offering the impressive head above the Möll of about 1,770 m. in a horizontal distance of only 3–4 km. The storage stage, therefore, is based on damming and interconnecting these lakes to supply peak-load machines in the valley.

The Reisseck run-of-river section is planned to divert the more important mountain streams, mainly on the south-west flank of the massif, at elevations ranging from 1,288·5 to about 1,500 m. Reservoirs have been constructed in the Mühlderferbach and on the Riekenbach, and a diversion tunnel is planned to take in the headwaters of the Zwenbergerbach on the south-east slope of the mountain. These waters are collected into a common penstock which is laid

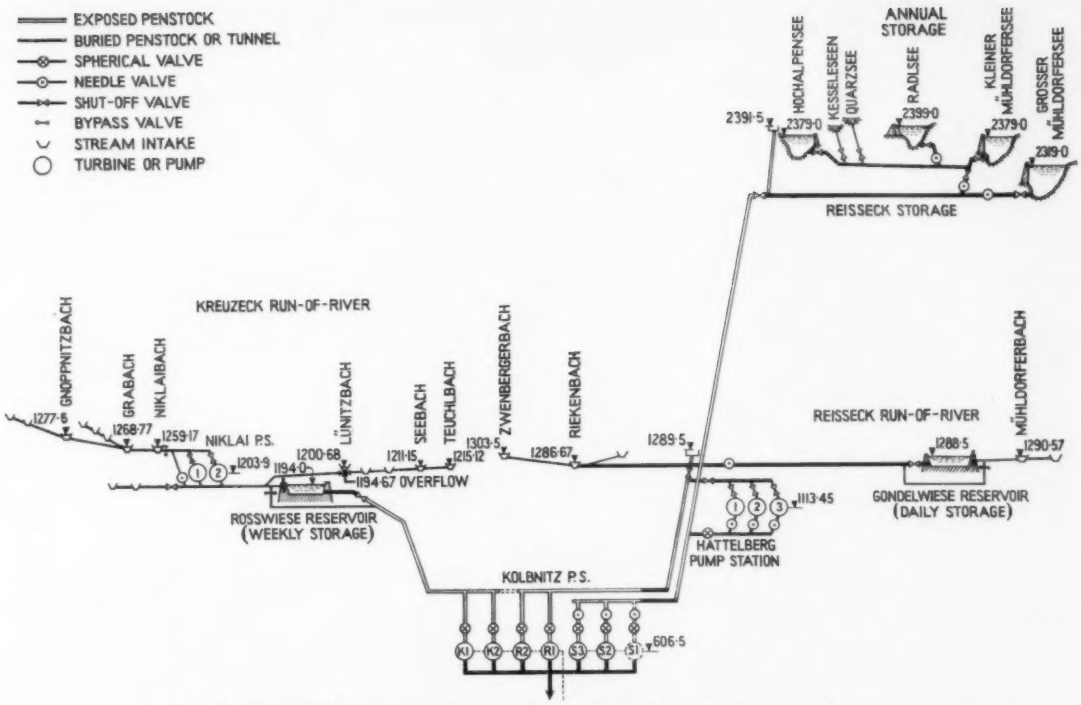


Fig. 3. Hydraulic-circuit diagram of the Reisseck-Kreuzeck development

by the side of that from the high-level storage, affording a head of 678·5 m. at the turbines.

Originally it was intended to divert the headwaters of the Gössbach by means of a tunnel through the Reisseck massif and to store them in a reservoir, to be known as Zandlacher reservoir, on the Riekenbach, for use in a local power station—Rieken station—of 8,000 kW capacity. Later, however, it was decided not to proceed with this feature of the scheme.

On the Kreuzeck side two diversion tunnels—one carrying the headwaters of the Teuchlbach and its tributaries and the other the headwaters of the Niklaibach—discharge to a reservoir at Rosswiese, whence a penstock descends to the valley, where a head of 587·5 m. is available. It is planned, also, to extend the Niklaibach tunnel to collect the headwaters of the Gnoppnitzbach and the Grabach, which flow southwards direct into the Drau.

The generating sets for all three sections are housed in a common power station at Kolbnitz in the Möll valley alongside the river. The somewhat unusual sight is thus presented of penstocks coming down both sides of the valley to serve a single station on the valley floor.

Natural storage in the high-level lakes is supplemented by water pumped up from a pumping station at Hattelberg, placed alongside the Reisseck penstocks at an elevation of 1,113·5 m. Normally the function of this station is to transfer surplus water from the Reisseck run-of-river section to the high-level storage, but an interconnection between the penstocks at Kolbnitz power station enables surplus water from the Kreuzeck section to be pumped to the Reisseck storage; also this interconnection enables surplus water from the Reisseck run-of-river section to be transferred by gravity to the Rosswiese reservoir on the Kreuzeck side. In this way the three sections of the scheme can be combined to form a most flexible entity to meet any foreseeable pattern of water flow or of electrical demand.

THE REISSECK STORAGE SECTION

The Reisseck storage section, as already indicated, is based on seasonal storage in four high-level lakes. These lakes have been impounded, according to their topography, at three different levels. The highest is Radlsee, which has a retention level of 2,399 m.; Hochalmsee and Kleiner Mühldorfersee have a common level of 2,379 m.; and Grosser Mühldorfersee is impounded to the lower level of 2,319 m. Grosser Mühldorfersee, which was the first reservoir to be completed, has a storage of 7·9 million cu. m., corresponding to an output of 30 GWh per annum; 3·8 million cu. m. of this storage is contributed by natural flow from a catchment area of 1·05 sq. km. and the balance is made up by pumping. The other three lakes have a combined storage of 10·1 million cu. m., corresponding to an output of 42 GWh per annum. Of this capacity, 8·18 million cu. m. derives from a catchment area of 6·72 sq. km. and the remainder by pumping. Thus the total high-level storage capacity is 18·28 million cu. m., of which 6·3 million cu. m. has to be filled by pumping.

The two Mühldorfer lakes can be seen in their natural state in our titleblock, Fig. 1, and during impounding in Fig. 5.

The High-Level Dams

Two general types of construction have been used for the dams for these four lakes—a semi-hollow concrete gravity type for the higher structures and a

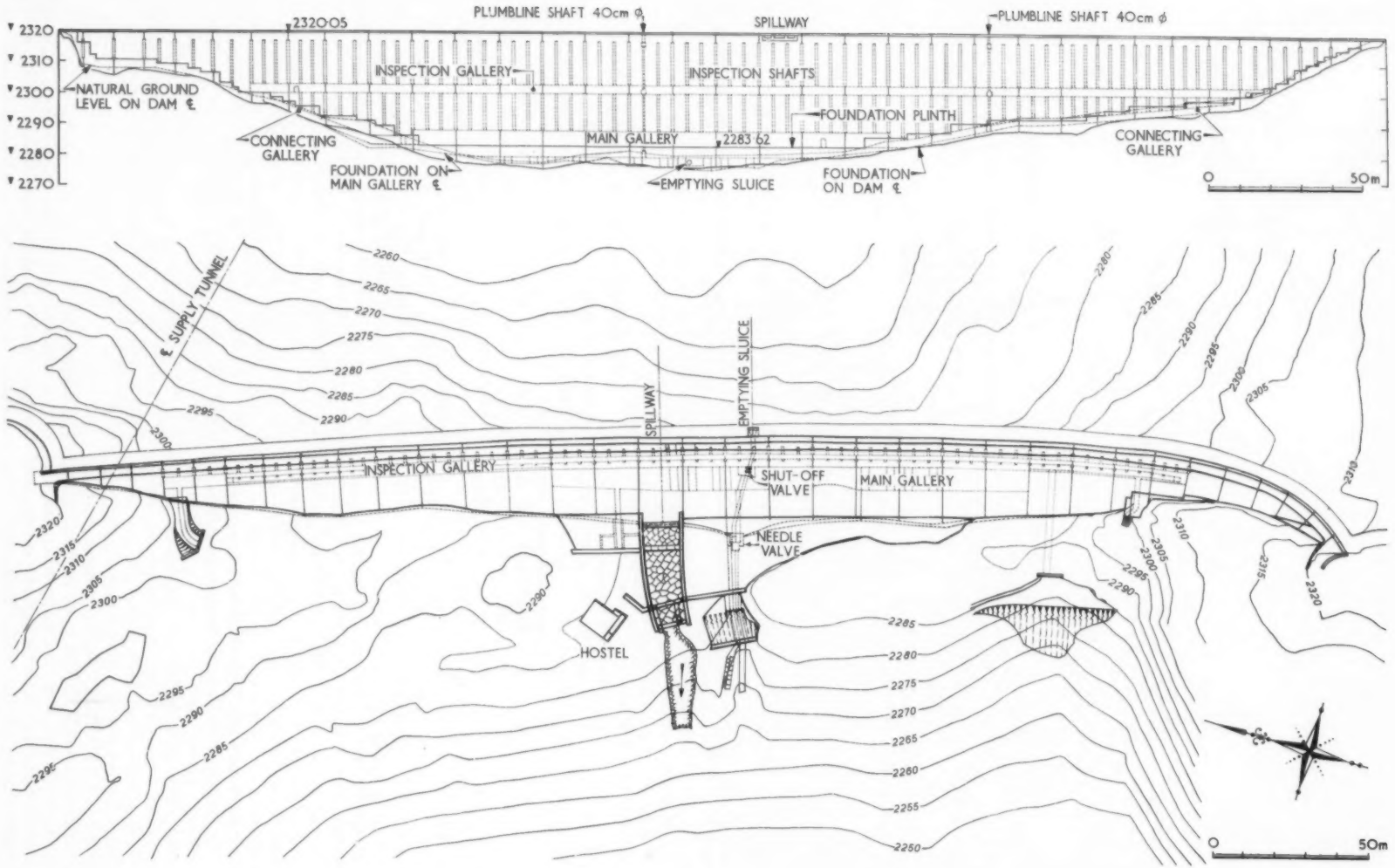


Fig. 4. Elevation and plan of Grosser Münldorfersee dam

Fig. 5. Kleiner Mühldorfersee dam under construction in the foreground, with Grosser Mühldorfersee reservoir and dam in the rear

rockfill type with concrete corewall for the lower ones.

Grosser Mühldorfersee dam, drawings and illustrations of which appear in Figs. 4, 6 and 9, is an example of concrete gravity construction. It is 430 m. long at crest, which is at an elevation of 2,320·05 m., and is 44 m. high above lowest foundation. It is curved in plan, the curvature being slight over most of its length but increasing sharply towards the left bank. The dam has been built in 32 blocks on a concrete plinth, and extending along the central portion of this plinth is an arched inspection gallery approximately 8½ m. high by 10 m. wide. About halfway up the dam is a second arched gallery, 2·75 m. high by 3·75 m. wide. This gallery is connected to the lower gallery by a series of inspection shafts, 0·7 m. in diameter and spaced at intervals of approximately 4 m., and a further series of inspection shafts rises from the upper gallery to nearly the crest of the dam. Two 0·4 m. diameter shafts for plumblines extend from the top to the bottom of the dam. At each end of the lower gallery a sloping gallery follows the line of junction of the foundation plinth with the rock until it reaches the upper gallery. The arrangement of all these galleries and shafts can be followed from the drawings.

The concrete for the foundation plinth was mixed with 225 kg. of cement per cu. m.; for the concrete enclosing the lower gallery the proportion of cement was reduced to 180 kg. per cu. m., and for the heart-

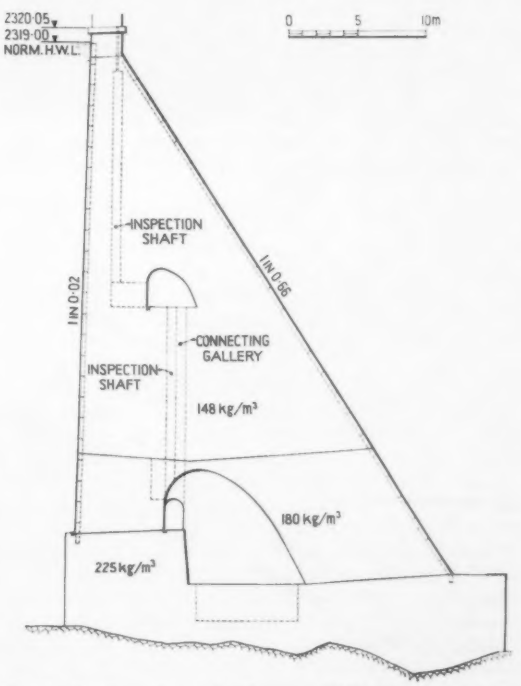
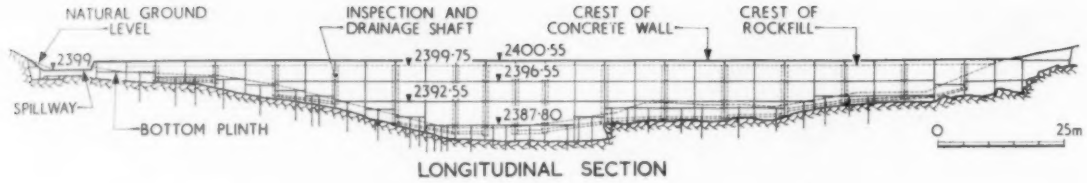
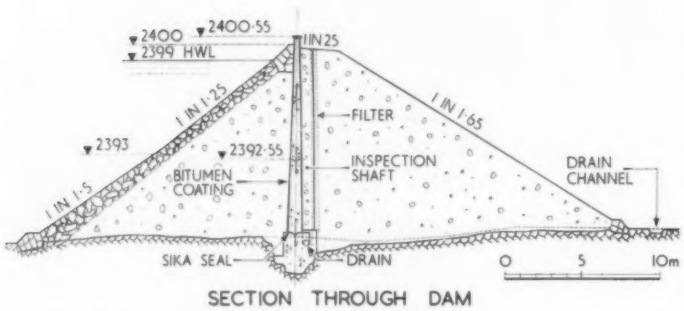


Fig. 6. Section through Grosser Mühldorfersee dam





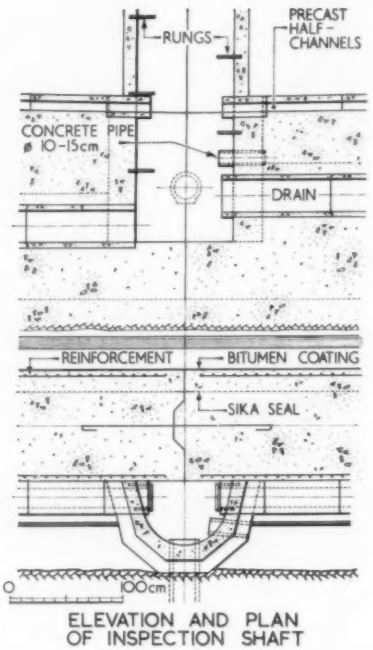


Fig. 7. Sections and details of Radlsee dam

ing concrete for the rest of the dam it was further reduced to 168 kg. per cu. m. Both the upstream and the downstream sides of the dam are faced with precast concrete plates.

A scour sluice, 0·9 m. in diameter, is cast into the foundation plinth at its lowest point, and at the centre of the crest is a free spillway with three openings having a total width of 8½ m.

Kleiner Mühldorfersee dam, seen under construction in Fig. 10, is generally similar in design to the one just described, but it is only 162 m. long at crest and 40 m. high from lowest foundation. The crest, which stands at 2,380·05 m., is straight except that the left-bank extremity is angled for a length of about 24 m.

Radlsee dam, sectional drawings of which are given in Fig. 7, is a rockfill structure with a reinforced-concrete corewall. The dam proper is 186 m. long at crest, and on the left bank is a spillway 10 m. wide. The crest, which is at a level of 2,400·55 m., rises clear of the rockfill on both upstream and downstream faces, and is 16 m. above lowest foundation.

The corewall is divided into 31 blocks, each 6 m. wide, and is carried on a foundation plinth set in a trench cut in the rock. Above this plinth the blocks are divided by horizontal joints into panels, mostly

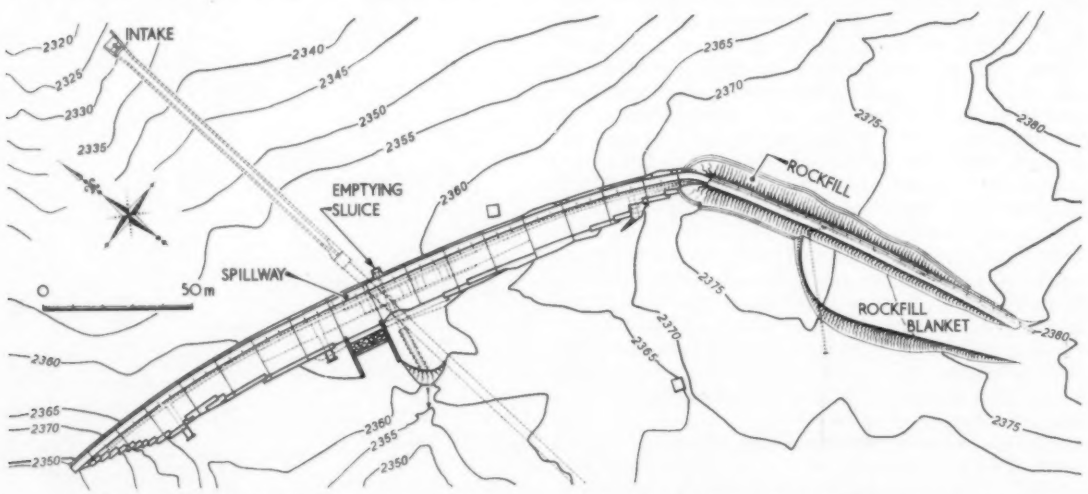


Fig. 8. Plan of Hochalmsee dam, which is a combined gravity and rockfill structure

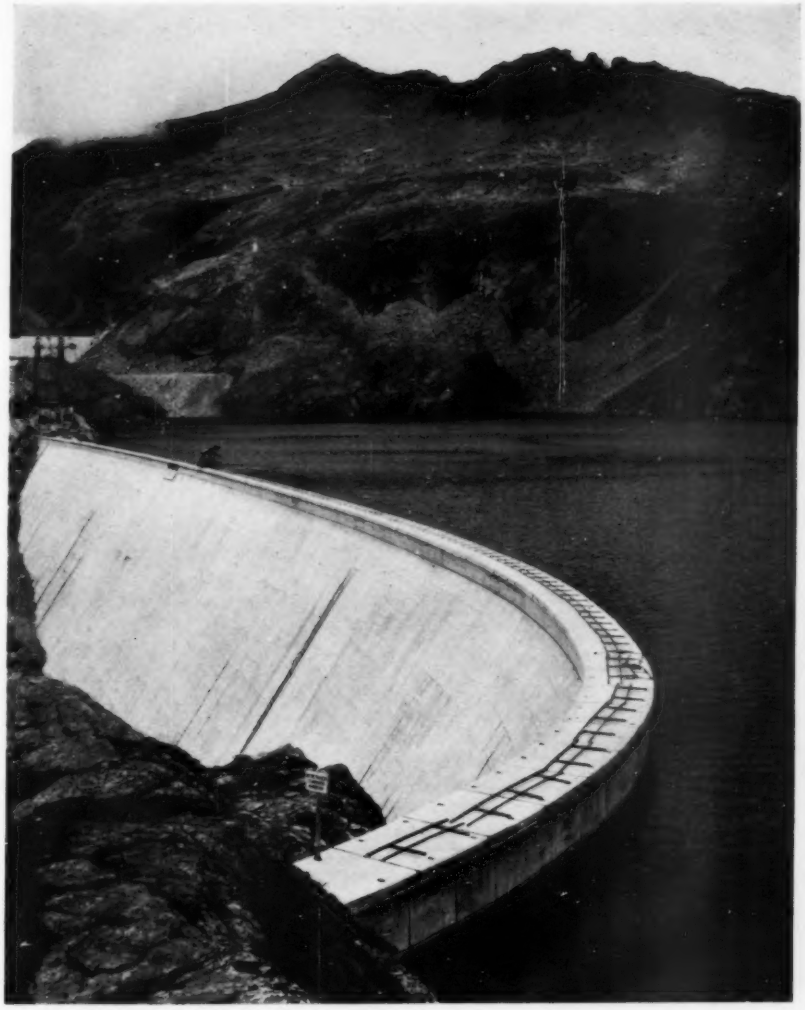


Fig. 9. Grosser Mühldorfersee dam completed

4 m. high. All joints are secured by Sika flexible seals, and the upstream face of the wall is coated with bitumen.

Behind the joints between alternate blocks—and between each of the centre three blocks—concrete inspection shafts have been constructed, as shown in Fig. 7. These shafts also act as collecting wells for the drainage system behind the corewall. Leakage from adjacent panels is led to each well by prefabricated concrete troughing, and the various wells are interconnected by drainage pipes which lead to discharge pipes at the centre of the dam. A filter blanket is also placed under the rockfill on the downstream side. On the upstream side the rockfill is faced with stone pitching consisting of boulders about 80 cm. in size, and the parapet is finished with hand-placed rock.

In the Hochalmsee dam (Fig. 8) we have a combined rockfill and concrete gravity structure. The reason for this is to be found in the profile of the site, which is shallow for about a third of its length towards the left bank and much deeper over the remainder. Thus the maximum height of the rockfill section is 8·5 m. and that of the concrete section 23·5 m. The construction of the concrete gravity section is essentially similar to that of the Grosser and Kleiner Mühldorfer dams, whereas the rockfill section is comparable to the Radlsee dam. A wide rockfill blanket, 3–4 m. thick, protects the rockfill section on the downstream side.

The concrete section of the dam was built in 17 blocks, mostly 14 m. wide, followed by a junction block 10·62 m. wide. Nineteen blocks, each 6 m. wide, constitute the concrete corewall of the rockfill section, making a total of 38 blocks. The dam is 357 m. long at crest.

Collecting Pipelines

A system of collecting pipelines conveys the waters from the foregoing reservoirs to a valve chamber on the Seen plateau, and from this point a further pipeline leads to a surge shaft and a second valve chamber at Schoberboden at the top of the penstock. The outlet from each reservoir is controlled by a shut-off valve followed by an automatic valve which closes in the event of a pipe burst and also operates in association with automatic air-inlet valves which guard against the formation of a vacuum in the pipe during normal closure. Any automatic valve can be closed from Kolbnitz power station, but must be opened locally. Testing equipment is also provided to check the automatic release gear. Under test this gear closes the valve about 10% and restores it without interrupting the flow.

The valves for the Grosser Mühldorfersee reservoir have a bore of 1,200 mm. and were supplied by Österreichische Armaturen Gesellschaft (ÖAG), Vienna. The same firm also supplied the valves for the Kleiner Mühldorfersee, which have a bore of 1,100 mm. For the Hochalmsee and Radlsee reservoirs the valves are of 700 mm. and 600 mm. bore respectively and were supplied by Maschinenfabrik Andritz, Graz.

The pipelines from the four lakes are partly buried and partly laid open in tunnel and have a total length of 5·6 km.; their diameters range from 550 mm. to 1,100 mm., and their wall thicknesses from 5 mm. to 10 mm. Their total weight is about 720 tons. A maximum operating pressure of 16 atm. has been taken

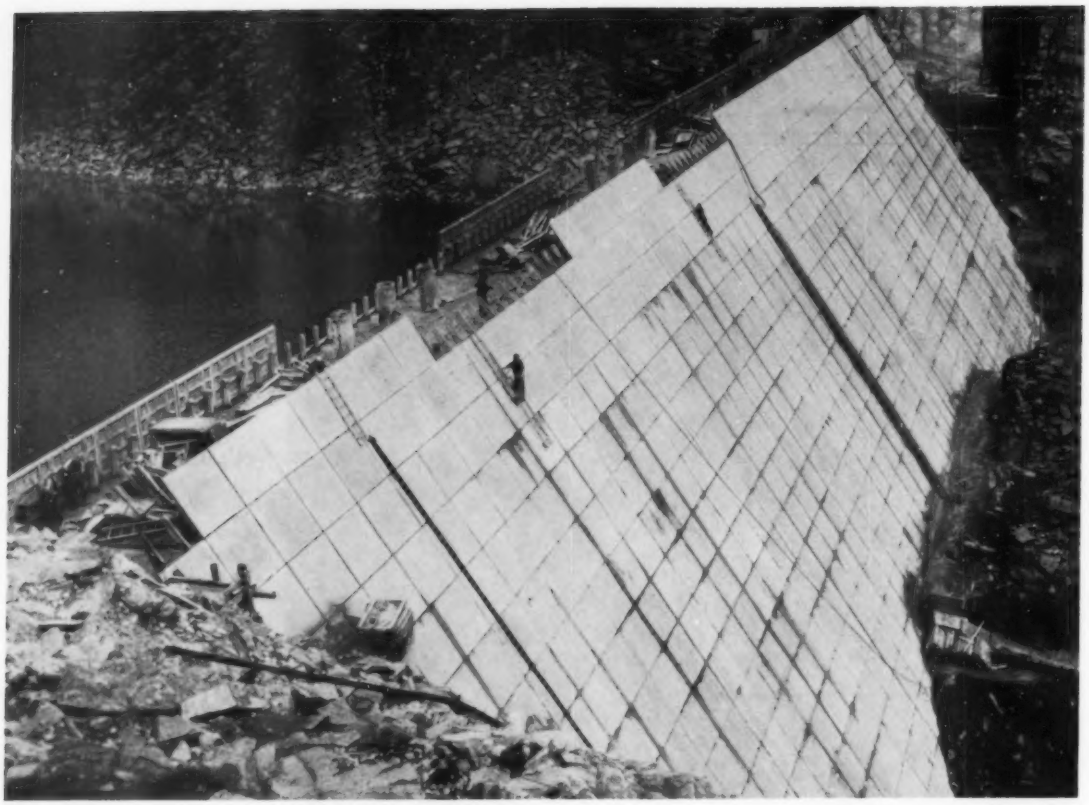


Fig. 10. Kleiner Mühldorfersee dam under construction

for design, this figure including an allowance of 10% for pressure surges. The maximum working stress in the steel has been kept within 0·52 of the guaranteed lowest limit of stress of the steel as delivered. Constructional steel St37T, in accordance with Austrian Specification ÖNORM 3115, has been used, and the pipelines have been welded throughout. The welds were controlled by X-ray and isotope examination both during production and during installation. The pipes were made by VÖEST, Linz, and Waagner-Biró, Graz, the latter firm also being responsible for the erection.

The valve chamber at the Seen plateau is located at the junction between the pipeline from the Grosser Mühldorfersee and that from the other three lakes. Flow from the Grosser Mühldorfersee is regulated by a spectacle-type sluice valve of 1,100 mm. bore. A similar valve regulates the flow from the other lakes, but is preceded by an automatic valve of 1,200 mm. bore. All these valves were supplied by ÖAG.

From the Seen-plateau valve chamber to the one at Schoberboden a pipeline extends, partly open in tunnel and partly buried, for a distance of 4·25 km. It has a diameter of 1,350 mm. and a wall thickness of 9 mm. and weighs 1,060 tons. Special Aldur 44 steel, supplied by VÖEST, was used, to withstand a maximum working pressure of 18 atm., including a 10% surge, the allowable stress and the control of production being as for the pipelines previously described. VÖEST and Waagner-Biró were the suppliers, the latter carrying out the erection.

Immediately below the Seen plateau valve chamber a surge pipe is branched off from the pipeline. This pipe, which is of Aldur 44 steel and was supplied and erected by VÖEST, is completely buried, is 450 m. long and weighs 120 tons. At the bottom its diameter is 1,350 mm.; higher up it reduces to 1,100 mm., and towards the top it increases again to 1,200 mm. The wall thickness ranges from 6 to 9 mm., and the maximum pressure at the bottom of the surge pipe is 18 atm. At the top, the pipe leads to a concrete spilling-type chamber.

The Schoberboden valve chamber at the head of the main penstock houses an ÖAG 1,400 mm. diameter automatic valve which closes if the water flow reaches 10% above normal, and can also be tripped by remote control from Kolbnitz power house. It can be opened only from the valve chamber, by operating a small oil pump. Seeing that the high-level reservoirs are used for pumped storage, this valve is arranged so that it will open 25% if water is pumped against the closed valve, and if the valve is inadvertently tripped while pumping is in progress it will close to only 30%. The usual air-vent valves are incorporated in the installation.

(To be continued)

Flygt Review. We have received a copy of the first issue of this house journal produced by Flygt International AB, Postfack, Solna 1, Sweden. It contains several interesting examples of the use of Flygt pumps in various parts of the World.

A New Approach to Load Curves

The author suggests a new method of representing load-duration curves which takes into account the variation in efficiency with load of the component parts of an installation. This first article applies the method to a consideration of true pumped-storage systems

By M. KAMAL GOHAR, M.Sc., Ph.D.*

PART ONE

IN any power system each station has its own characteristics, and it is hardly possible to find two power stations that have the same load curves. Previous authors[1] have represented the load-duration curves analytically by equations that depend on the maximum and minimum demands, together with the load factor only. Such representations do not always give correct results. Fig. 1 represents two different load-duration curves *a* and *b*, each of which has the same maximum and minimum demands and the same load factor; but obviously they could not be represented by the same formula. Moreover, the analysis previously used depended on trial-and-error methods, which may take a considerable time, especially if the equivalent effective efficiency for the whole system is to be determined. In this paper a new quick representation for the load-duration curves is suggested, and its application in cases of true pumped-storage schemes is given. Theoretical results have been obtained rapidly, and they are in good agreement with the practical results. A comparison between the solutions of previous authors and the suggested method is also made here.

As far as the author is aware, this is the first time that the variation of the effective efficiency with relation to the power consumed has been taken into account in treating problems of this kind.

Purpose of the Method

A true pumped-storage scheme is the one where the total amount of water passing through the turbines is equal to the total amount pumped; the turbine and the pump would have the same gross head. Examples of schemes of this kind are Ffestiniog, in Wales, and Lac-Blanc Lac-Noir in France.

Dr. Charles Jaeger[1] recommended two mathematical equations (1) and (2) to represent the load-duration curves:

$$P = P_{max}\left[\theta_0 + \frac{2}{\sqrt{\pi}}(\theta - \theta_0)\left(\log\frac{T}{t}\right)^{\frac{1}{2}}\right] \quad \ldots (1)$$

based on the probability theory, and

$$P = P_{max}[1 - (1 - \theta_0)t^{\theta - \theta_0/1 - \theta}] \quad \ldots (2)$$

the formula of Soschiniski,
where $\theta_0 = P_{min}/P_{max}$; P = load at the time t; P_{max} = maximum load; P_{min} = minimum load; θ is the load factor; T is the period considered, and t/T is the relative time. In equation (2), t is the relative time ($T = 1$). In both cases it can be seen that the mathematical expressions of equations (1) and (2) depend on the values of P_{max}, P_{min} together with the load factor θ in a given time T. This does not always lead to correct results; e.g., in Fig. 1 the two curves *a* and *b* represent load-duration curves both having the same values of P_{max}, P_{min} and θ for the same time T but obviously they would not have the same mathematical expressions. Another practical application is the load-duration curves shown in Figs. 2 and 4[2,3,4].

Dr. C. Jaeger[1] preferred to work with equation (2) of Soschiniski, and his method led to the use of equations requiring to be solved by trial and error, which may take a long time. The efficiencies of the pumps and turbines were assumed to be constant without indicating how such a mean effective constant value could be chosen; it would be more convenient if the mean effective efficiencies of the elements of the system could be determined and applied.

Thus a need is felt in such cases to find another representation for all kinds and shapes of practical load-duration curves which can be determined easily and quickly, from which the mean effective efficiency values of the system components can be estimated directly, as they affect the corresponding results to a considerable extent.

Theoretical Analysis

From the different characteristic load-duration curves shown in Figs. 2 and 4, it can be seen directly that they can satisfactorily be represented by three straight lines *ab*, *bc*, and *cd* as shown in Fig. 3, in which *ab* and *cd* are parallel to the time axis; *ab* corresponds to time t_1, *cd* to time t_2 and *bc* to time t_3. The period considered

$$T = t_1 + t_2 + t_3 \quad \ldots (3)$$

The values of t_1, t_2 and t_3 depend on the shape of the load-duration curve, which can be easily determined. In general the discrepancy between the actual load-duration values and the corresponding representative ones can be adjusted here to be less than 7%; it is well known that the actual load-duration curves are usually subjected to such an order of variation. If the areas made by each actual load-duration curve and its representative one with the power and time axes are the same—i.e. the load factor in both cases can be considered the same—then, as will be seen later, this kind of representation for the load-duration curves will be more convenient in the analysis and calculations. The representation of the load-duration curves shown in Figs. 2 and 4 shows how the times t_1, t_2 and t_3 can be

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properly chosen to represent satisfactorily the corresponding figure.

Applications

DETERMINATION OF THE LOAD FACTOR θ

According to Fig. 5, if *abcd* represents the load-duration curve in time T, the corresponding load factor

$$\theta = \frac{\text{area } oabcdd'}{\text{area } oajd'} = \frac{\text{area } oafh + \text{area } hgdd'}{P_{max}T}$$

$$= \frac{P_{max}(t_1 + t_3/2) + P_{min}(t_2 + t_3/2)}{P_{max}T} \quad \ldots (4)$$

Equation (4) is very simple and easily calculated.

WATER ENERGY FOR TRUE PUMPED-STORAGE SCHEMES WHEN THE BASE LOAD FACTOR = 1

Three cases will be considered here:

(a) The losses are neglected and the efficiencies are assumed = 100%.

(b) Overall efficiency of the system = η including the pumps, turbines, pipes, etc., assuming it to be constant.

(c) The efficiency of the system varies with the load.

Case (a)

According to Fig. 6, if *abcd* represents the load-duration curve in time $T = t_1 + t_2 + t_3$, then it is required to determine the line *efg* so that the area *eabf* representing the generated energy by the turbines = area *cfgd* for a true pumped-storage system and for an efficiency of 100%.

If $k = P_{max} - P_{min}$ and *ae* represents the maximum power of the turbines P_{tm}, then $k - P_{tm} = P_{pm}$, the corresponding maximum power of the pumps which is represented by *gd*. As area *eabf* = area *cfgd*, then

$$P_{tm}t_1 + P_{tm}^2 \frac{\tan\beta}{2} = (k - P_{tm})t_2 + (k - P_{tm})^2 \frac{\tan\beta}{2} \quad \ldots (5)$$

and hence

$$P_{tm} = \frac{kt_2 + k^2 \dfrac{\tan\beta}{2}}{T}, \quad \text{where} \quad k\tan\beta = t_3 \quad \ldots (6)$$

Case (b)

Instead of line *efg* in Fig. 6, it is required in this case to determine another line, such as *e'f'g'* in Fig. 7, so that the area $e'abf' = \eta \times$ area $cf'g'd$, i.e.:

$$P_{tm}t_1 + P_{tm}^2 \frac{\tan\beta}{2} = \eta\left[(k - P_{tm})t_2 + (k - P_{tm})^2 \frac{\tan\beta}{2}\right] \quad \ldots (7)$$

This is a quadratic equation in P_{tm} and the required solution is given by

$$P_{tm}t = \frac{-[t_1 + \eta(t_2 + k\tan\beta)] + \sqrt{\{[t_1 + \eta(t_2 + k\tan\beta)]^2 + \eta(1-\eta)\tan\beta(2kt_2 + k^2\tan\beta)\}}}{(1-\eta)\tan\beta} \quad \ldots (8)$$

If η is very near to unity, equation (8) can be satisfactorily approximated to

$$P_{tm} = \frac{\eta(kt_2 + \dfrac{k^2}{2}\tan\beta)}{t_1 + \eta(t_2 + k\tan\beta)} \quad \ldots (9)$$

It should be noted that if $\eta = 1$, equations (6) and (9) are equal.

Case (c)

In fact η is not constant for the different powers of the various elements. In this case the solution can be obtained satisfactorily in three steps; but usually two are quite sufficient.

The First Step (*First approximation*). Neglect the losses at first, i.e. considering the overall efficiency = 100%. In this case the line *efg* in Fig. 8 can be determined by using equation (6).

The Second Step (*Second approximation*). If the area *fgdcf* in Fig. 8 represents the electrical energy used for pumping in a case of a true storage scheme, the actual water energy pumped will be less than this quantity by an amount that depends on the efficiency of the pumps and on friction losses of the system. By knowing the variation of these losses with the power consumed, the area *fgd'c'f* can be easily determined, representing the actual water energy pumped. It should be noticed here that the part *d'c'* is a line parallel to *dc* whereas the part *c'f* is generally a curve, as the efficiency is not constant with the power variation. Usually a line such as c'_1f_1 parallel to the line *bfc* can be drawn giving the mean effective representation for the part *c'f* if the area *fgd'c'f* = area $f_1gd'c'_1f_1$. The problem is now reduced to determining a line such as *e'f'g'* so that the area *abf'e'a* =

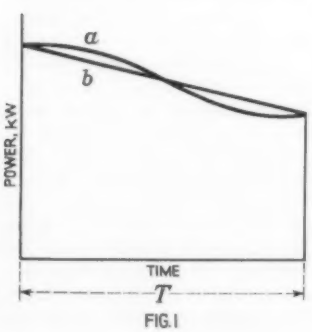


FIG.1

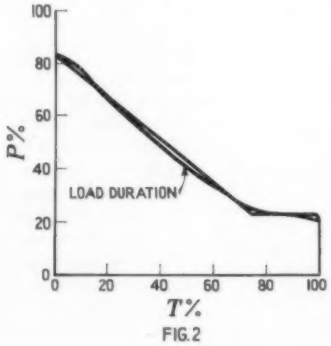


FIG.2

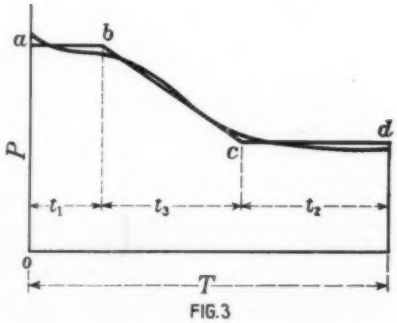


FIG.3

area $f'_1g'd'c'_1f'_1$ representing the water energy pumped and available for the turbines if no leakage or evaporation exists. We can imagine that the line c'_1f_1 in Fig. 8 is moved to the left until it coincides with *bfc*.

Similarly to equation (6), the maximum turbine power P'_{tm}, represented by ae', can be calculated from Fig. 8 or from equation (10).

$$P'_{tm} = \frac{k't'_2 + \frac{k'^2}{2}\tan\beta}{T'} \qquad \ldots (10)$$

where k' = power ordinate between ab and $c'd'$; t_2' = time between c'_1 and d'; $T' = t_1 + t'_2 +$ time between b and $f +$ time between f_1 and $c'_1 = t_1 + t'_2 + t'_3$; $[t'_3 = k' \tan \beta]$

Third Step (*Third approximation*). Taking $e'f'g'$ as the base line instead of line *efg* in the preceding step, and following the same analysis, a solution of the third approximation can be obtained by having $d''c_1'' f_2$ instead of $d'c_1'f_1$, etc., but usually the second approximation will be sufficient due to the relatively high efficiency of the system in general.

The corresponding electrical-energy output from the turbines at peak loads is usually less than the area $abf'e'$ shown by an amount depending on the efficiency of the generating system. A curve such as $a'b'f'$ will represent the corresponding electrical-power output by knowing the variation of the efficiency of such a generating system with relation to the power variation. The electrical energy needed for pumping and that generated in this case are illustrated also in Fig. 8.

(Case (b) can be considered as a special correlation of case (c).)

Water Energy and Power for a True Pumped-Storage Scheme when the Base Load Factor $\theta_b < 1$

As in the previous section, the three cases, *a*, *b*, and *c* will be considered here also.

Referring to Fig. 9, suppose that *abcd* represents the load-duration curve for a total time T. The maximum and minimum powers of the system are P_{sm} and P_{si} respectively, and θ_s is the load factor of the system. If it is required to determine the true pumped-storage energy when the base load factor $\theta_b < 1$, it will be assumed that the base load-duration curve will have the same values of t_1, t_2 and t_3 as those of the power-system load-duration curve. (In comparison with Dr. Charles Jaeger's work[1], he also mentioned in his paper that such a value for the base load factor alone could not determine the shape of the corresponding load-duration curve and hence a convenient shape has to be suggested.) Hence the analysis for the three cases *a*, *b*, and *c* in this section can be illustrated as follows:

Case (*a*)

According to Fig. 9 and for a true pumped-storage system, it is required to determine the load-duration curve *fgmhl* which satisfies the following conditions:

The area of *fabmgf* = the area of *cmhldc* ... (11)

The load factor of *fgmhl* = θ_b ... (12)

Also if the time between points b and $m = t_3/2 + \Delta$, then the time between points m and c will be

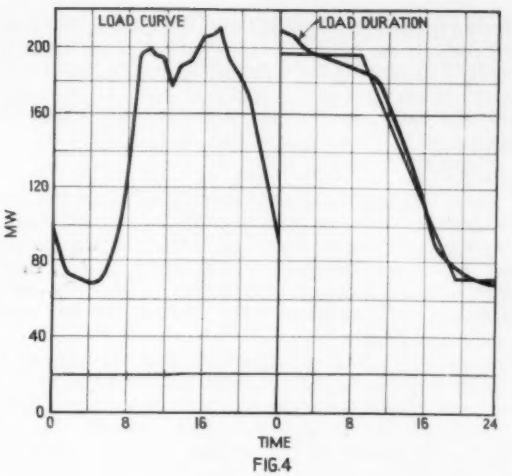


FIG.4

$$\frac{t_3}{2} - \Delta \qquad \ldots (13)$$

where $\Delta < t_3/2$; and Δ may be a positive or a negative value as will be illustrated later.

From equations (11) and (13) we get:

$$P_{tm}t_1 + P_{tm}\frac{t_3/2 + \Delta}{2} = P_{pm}t_2 + P_{pm}\frac{t_3/2 - \Delta}{2} \qquad \ldots (14)$$

From Fig. 9 it can be seen that

$$P_{tm} + P_{bm} = P_{sm} \qquad \ldots (15)$$

and

$$P_{si} + P_{pm} = P_{bi} \qquad \ldots (16)$$

From equations (4), (12), (15) and (16)

$$\theta_b = \frac{(P_{sm} - P_{tm})(t_1 + t_3/2) + (P_{si} + P_{pm})(t_2 + t_3/2)}{(P_{sm} - P_{tm})T} \qquad \ldots (17)$$

Again as *bmc* and *gmh* are straight lines, then by the use of equation (13)

$$\frac{P_{pm}}{P_{tm}} = \frac{t_3/2 - \Delta}{t_3/2 + \Delta} = \lambda \qquad \ldots (18)$$

Equations (14), (17) and (18) are three equations in the three unknowns P_{tm}, P_{pm} and Δ. The solutions of equations (14) and (18) are given in Appendix I from which

$$\Delta = \frac{t_3}{2}\frac{t_2 - t_1}{T} \qquad \ldots (19)$$

and

$$\lambda = \frac{P_{pm}}{P_{tm}} = \frac{2t_1 + t_3}{2t_2 + t_3} \qquad \ldots (20)$$

Substituting the value of P_{pm} from equation (20) in equation (17), P_{tm} can be determined directly.

From equations (19) and (20) it is seen that when $t_2 > t_1$, Δ will have a positive value and $\lambda < 1$. When $t_2 = t_1$, $\Delta = 0$ and $\lambda = 1$. When $t_2 < t_1$, Δ is negative and $\lambda > 1$.

Case (*b*)

Here equation (11) will be substituted by:
The area of *fabmgf* = η (the area of *cmhldc*)

where η is the overall efficiency of the system, which is assumed to be constant. This case can be treated similarly to case (*b*) in the preceding section, but it will not be given here as for practical purposes η varies with the load consumption, and even so, it can be considered as a special condition of case (*c*).

Case (*c*)

As in the previous section, the solution can be obtained in three steps, and generally two are sufficient.

First Step (*First approximation*). Neglecting the losses, and considering the overall efficiency = 100%, then by the use of equations (17) and (20), P_{tm} and P_{pm} can be determined, and *fgmhl* in Fig. 10 represents the base load factor in such case.

Second Step (*Second approximation*). If the area *mhldcm* represents the electrical energy required for the true pumped-storage system, the actual water energy pumped is less than this quantity by an amount depending on the pumping-system efficiency. Let *mhld'c'm* represent this energy. In this case also, *d'c'* will be parallel to *dc*, whereas part *c'm* is generally a curve, as the efficiency is not constant with the power variation. Usually a line such as c'_1m_1 parallel to *cmb* can be drawn giving the mean effective representation for the part *c'm* if the area of *mhld'c'm* = the area of $m_1hld'c'_1m_1$.

The problem, therefore, is now reduced to determining the load-duration curve $f'g'm'h'l'_1$ of load factor θ_b so that the area $abm'g'f'a$ = the area $m'h'l'_1d'_1c'_2m'$. Each represents the water energy pumped and given to the turbines if no leakage or evaporation exists. [l'_1l' = horizontal distance between c'_1m_1 and *cm*].

Equations (21), (22) and (23) here can be deduced in a similar way to equations (17), (19) and (20) respectively.

$$\theta_b = \frac{(P_{sm} - P'_{tm})(t_1 + t'_3/2) + (P_{si} + P'_{pm})(t'_2 + t'_3/2)}{(P_{sm} - P'_{tm})T'} \quad \ldots (21)$$

$$\Delta' = \frac{t'_3}{2}\frac{t'_2 - t_1}{T'} \quad \ldots (22)$$

$$\lambda' = \frac{P'_{pm}}{P'_{tm}} = \frac{2t_1 + t'_3}{2t'_2 + t'_3} \quad \ldots (23)$$

where P'_{tm} = the maximum turbine power in this case and represented by af'

P'_{pm} = the maximum pumping power in this case and represented by $l'd'$

t'_2 = the time between c'_1 and $d' = c'_2d'_1$

$t'_3 = t_3$ — the time between c and $c'_2 = bc'_2/bc \cdot t_3$

$T' = t_1 + t'_2 + t'_3$

We can imagine that the line c'_1m_1 is moved to the left until it coincides with the line *bmc*.

Third Step (*Third approximation*). Taking $f'g'h'l'$ as a reference instead of *fghl* and following a similar analysis to the preceding one, a third-approximation solution can be obtained by using $f''g''h''l''$ instead of $f'g'h'l'$, etc.; but usually the second approximation is sufficient due to the relative high efficiency of the system.

The corresponding electrical energy generated from the turbines is less than the area of $abm'g'f'a$ when the efficiency of the generating system is taken into account. If the variation of this efficiency with respect to the power input is known, the corresponding electrical power output can be determined and represented by $a'b'm'g'f'a'$.

As far as the author is aware, this is the first time that problems of this kind have been solved analyti-

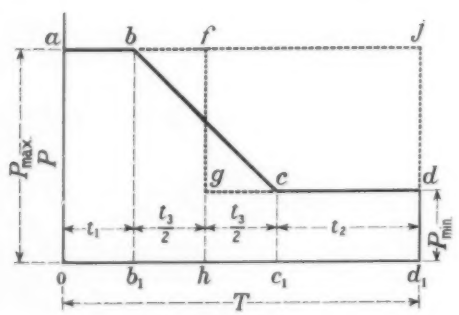


FIG.5

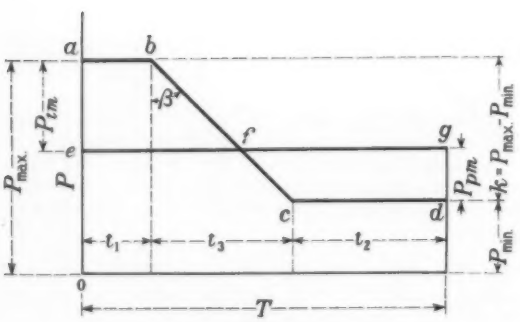


FIG.6

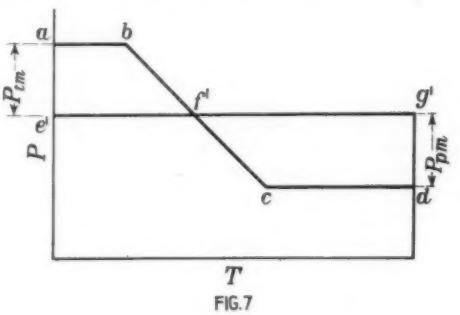


FIG.7

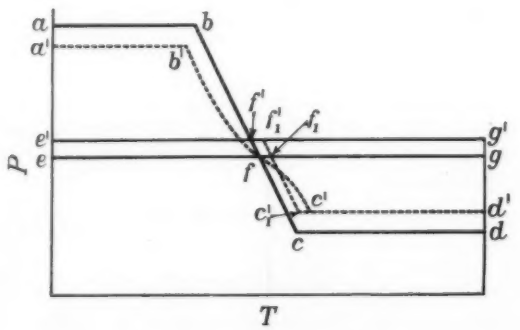


FIG.8

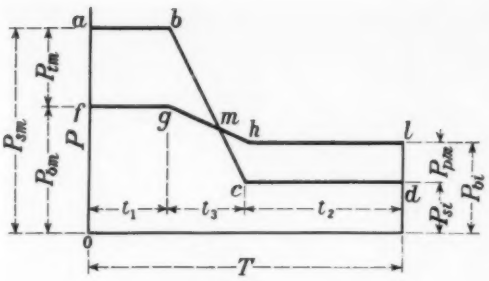


FIG.9

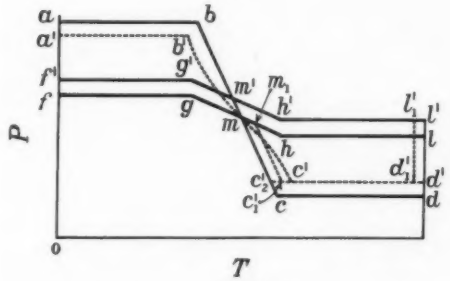


FIG.10

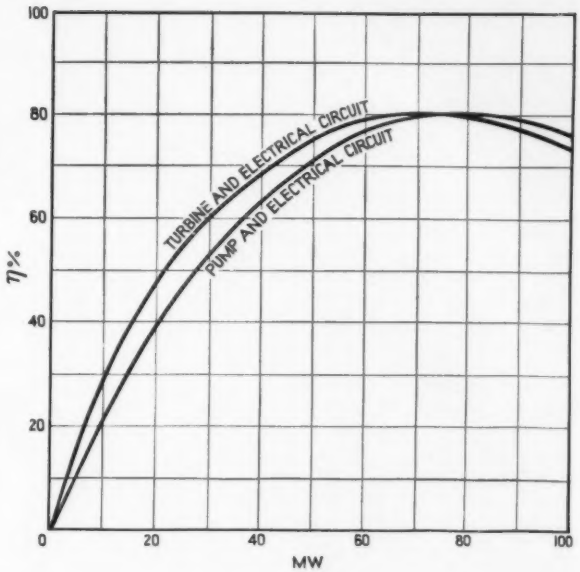


FIG.11

cally taking into consideration the variation of the efficiency of the system when the load is changing.

Practical Verifications

Referring to Fig. 4, the representation of the load-duration curve gives $P_{max} = 200$ MW; $P_{min} = 70$ MW; $t_1 = 10$ hours; $t_2 = 5$ hours and $t_3 = 9$ hours.

From equation (4),

$$\text{the load factor } \theta = \frac{200(10 + 4{\cdot}5) + 70(5 + 4{\cdot}5)}{200 \times 24}$$

$$= 0{\cdot}745 \qquad \ldots (24)$$

(The percentage error is less than 5%.)

In the case of a base load factor = 1 and assuming the efficiency curves of the pumping and turbine systems, including the electrical circuit losses, to be as represented in Fig. 11, then the procedure may be as follows:

First Step. Assuming the efficiency = 100%, then by the use of equation (6)

$$P_{tm} = \frac{130 \times 5 + 130 \times 9/2}{24} = 51{\cdot}46 \text{ MW} \quad \ldots (25)$$

where $k = 200 - 70 = 130$ MW

$$P_{pm} = 130 - 51{\cdot}46 = 78{\cdot}54 \text{ MW} \quad \ldots (26)$$

Second Step. From Fig. 11, the pumping-system efficiency at 78·54 MW = 81%, i.e. the percentage loss = 19%. Then

$$k' = 130 - 0{\cdot}19 \times 78{\cdot}54 = 114{\cdot}96 \text{ MW} \ldots (27)$$

$t'_2 = 5{\cdot}35$ hours, $t'_3 = 8{\cdot}31$ hours, and

$T' = 10 + 5{\cdot}35 + 8{\cdot}31 = 23{\cdot}66$ hours.

Then by equation (10),

$$P'_{tm} = \frac{114{\cdot}96 \times 5{\cdot}35 + 114{\cdot}96 \times 8{\cdot}31/2}{23{\cdot}66}$$

$$= 45{\cdot}9 \text{ MW} \qquad \ldots (28)$$

$$\text{hence } P'_{pm} = 114{\cdot}96 - 45{\cdot}9 = 69{\cdot}06 \text{ MW} \qquad \ldots (29)$$

As the assumed pumping efficiency = 81% then the maximum power input to the pumping system

$$= \frac{69{\cdot}06}{0{\cdot}81} = 85{\cdot}5 \text{ MW} \qquad \ldots (30)$$

(It could be seen from Fig. 11 that at a power of 85·5 MW the efficiency is between 81 and 82%, so that there is no need for the third approximation as already stated before.)

In comparison with Dr. Jaeger's work[1], Fig. 14 of his paper will be in good agreement with the method suggested here if $t_1 : t_2 : t_3 = 1 : 3 : 5$ only; otherwise a considerable difference between the two methods will appear. The same can be said for other cases.

Conclusions

Unless load-duration curves are represented precisely they may lead to incorrect results. A quick and precise new representation for all types of practical load-duration curves has been suggested here, and its applications to true pumped-storage schemes have been shown. The practical results were in good agreement with the theoretical values, and were calculated in a relatively short time in comparison with the other systems generally applied in such cases. Moreover, as far as the author is aware, this is the first time that problems of this kind have been solved analytically, and have taken into consideration the efficiency variation of the system when the load is changing.

This method of representation can be used with advantage also in treating other kinds of economical power problems, e.g. the determination of the maximum energy output for a given power system.

Acknowledgment

The author would like to express his appreciation and thanks to ANIDEL (The Association of Italian

(Continued on page 201)

Fig. 21. Valgrosina dam seen from the right bank

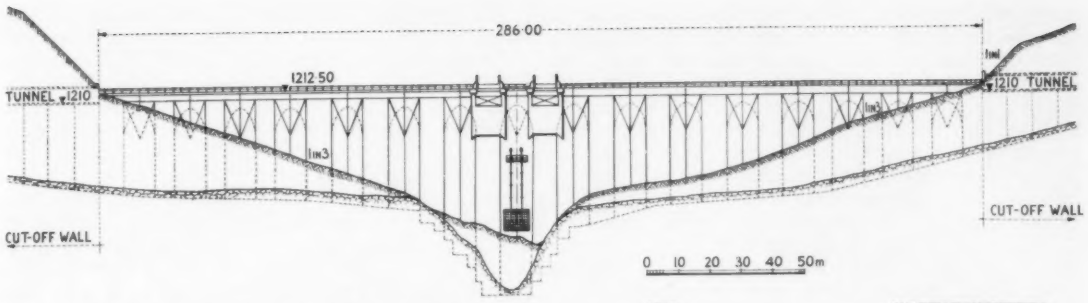
The Valtellina Development

In this final article we describe Grosio station, the first phase of which entered into service in the spring of 1960

PART THREE

SOME 28 km downstream from Premadio is the largest station in the system and the latest to be built. This station, which is adjacent to the old Roasco station ultimately to be abolished, is known as Grosio and will have an ultimate capacity of 428 MW as against Premadio's ultimate capacity of 375 MW. The first stage, of 200 MW, was brought into commission in the spring of 1960. When warranted by the increase in demand, Cancano dam will be raised to its final height, the headwaters of the Spöl diverted into it, and the remaining capacity installed in Premadio and Grosio stations. At present Grosio station has a generating capacity in an average year of 716 GWh, and when the additional works just mentioned have been completed the figure will be raised to 852 GWh.

For the following description reference should be made to the map of the system given in Fig. 4 of our first article, which shows the general layout of the Grosio development and the sources of the waters supplying the station. The major supply consists of the Premadio tailwater, which is collected from the tailrace channel by an intake leading to the Grosio supply tunnel, as seen in Fig. 24. Certain other waters are also conducted to the supply tunnel by means of appropriate intakes. An intake in the main river bed of the Adda (Fig. 25) collects any flow made below the level of Cancano reservoir and also any spillage from the reservoir. A second intake in the bed of the Viola receives the run-off from the Viola Valley below the level of the tunnel diverting the headwaters to Cancano reservoir. The present diversion tunnel is at a level of 1,857 m, but as explained in our first article, a new tunnel is to be built at a level of 1,902 m, enabling the old Fraele station to be shut down. On the eastern side the headwaters in the Valfurva Valley have also been diverted to Cancano reservoir, as explained in an earlier article, and the run-off accumulating below the level of this diversion is routed to the Grosio supply tunnel through an intake on the Frodolfo. In order to place this intake at an appropriate elevation it has been necessary to con-



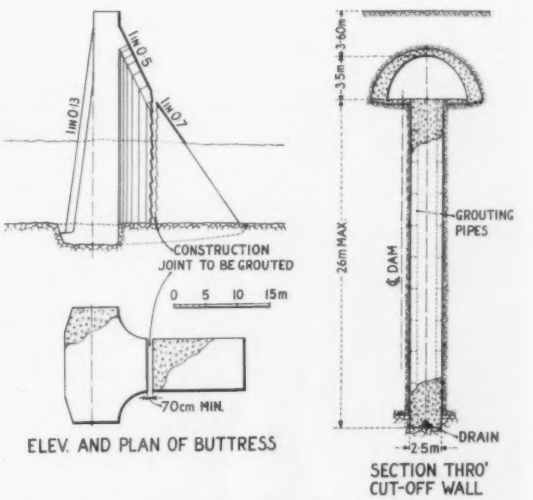


Fig. 22 (above). Upstream elevation of Valgrosina dam; (right) buttress elevation and plan and section through one of the flank cut-off walls

struct a branch tunnel from the intake to meet the main tunnel about 4·6 km from the portal.

Three side intakes trap the headwaters of certain mountain streams along the course of the main supply tunnel. This tunnel discharges into a new reservoir, of 1,400,000 m³ capacity, in the Valgrosina, constructed on the Roasco immediately above an older reservoir, of 200,000 m³ capacity, at Fusino, supplying the old Roasco station. A pressure tunnel leads from the new reservoir to a surge chamber and to the penstocks serving Grosio station, which is of the underground type. A bypass tunnel enables waters to be passed direct from the supply tunnel to the pressure tunnel without entering the reservoir.

The various parts of the development will now be described in greater detail.

Supply Tunnel

The Grosio supply tunnel, which has been driven in the right bank of the Adda, is of the free-flow type, but is designed so that it can run full under a moderate pressure when the level in Valgrosina reservoir rises above the tunnel mouth. The initial length, which is 384 m long, is designed for a flow of 39 m³/sec, consisting of the Premadio tailwater and the diversions from the Adda and the Viola.

The Adda and Viola intake works are similar in design and comprise a fixed overfall weir, a lateral gravel trap, a normal intake protected by an inclined grille, a low-level winter intake, and finally a desilting basin. The Adda intake is designed to withdraw 10 m³/sec and to pass a maximum flood of 340 m³/sec, and the Viola intake to withdraw 14 m³/sec and pass a flood of 325 m³/sec.

This initial length of the tunnel is of horseshoe section having an equivalent diameter of 4·20 m, a cross section of 14·63 m², and a slope of 1·7 m/km. Just before this part of the tunnel joins the main tunnel section, a regulating weir has been built having a crest 63·8 m long at an elevation of 1,222·15 m. At the junction point provision has been made for the discharge from the future second phase of the Premadio station to enter the tunnel, having been brought across the Adda by means of an aqueduct.

The main length of the tunnel, 20·680 km, is designed for a flow of 67 m³/sec, and is of horseshoe section, 4·94 m in equivalent diameter, 20·24 m² in cross section, and having a slope of 1·15 m/km.

It was not an easy task to determine the most suitable line for the tunnel, having regard to head-loss requirements, the time available for construction, the number and lengths of adits, and the nature of the rock to be traversed. The tunnel passes through no less than eleven different rock formations and some thirty principal faults in addition to numerous minor frac-

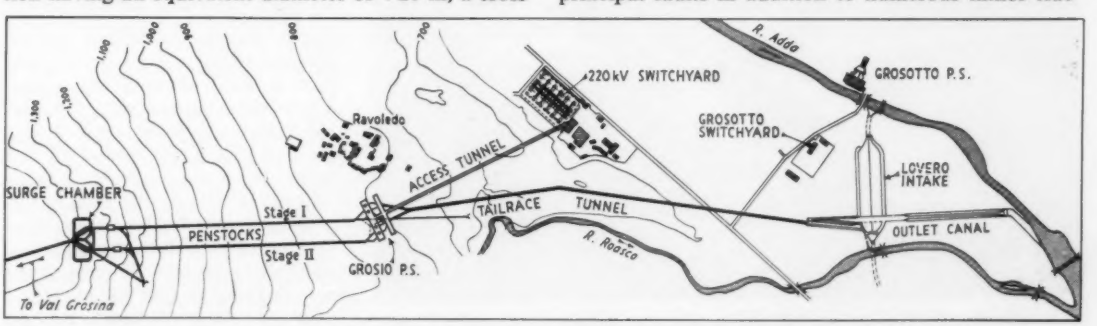


Fig. 23. Plan of Grosio station and associated works

tures. All the rocks, in fact, were badly fractured by tectonic forces and eroded by external morphological action. About 30% of the tunnel was driven in micaceous schist, another 30% in gneiss, and the remainder in intrusive rocks. Furthermore, it was necessary to plan the work so as to avoid upsetting the regime of certain mineral streams.

No less than seven adits, ranging in length from 100 to 479 m, were driven to form 14 working faces. Four of these adits have been retained permanently; the first of these, at Zola, has been lined with reinforced concrete to form the inlet for the Frodolfo waters, and the three others, which are shut off by self-sealing doors, afford access to the side inlets for the Massaniga, Vendrello and Migiondo streams.

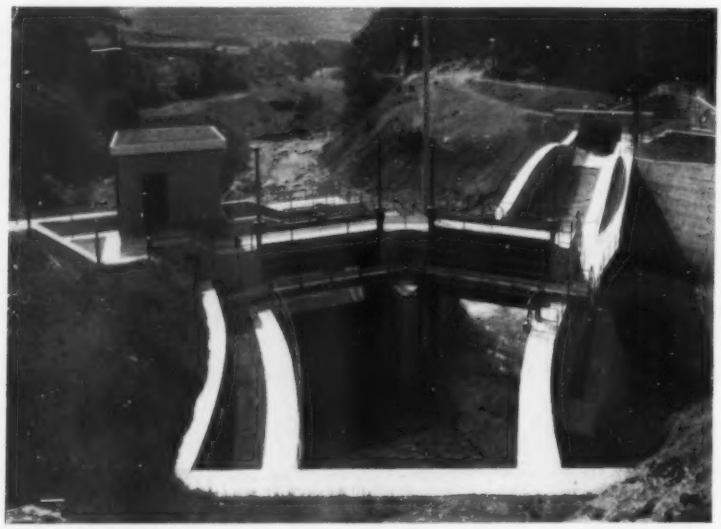


Fig. 24. Premadio discharge works. The aqueduct to the right leads to the Valgrosina supply tunnel; the gate to the left returns overflow to the Viola

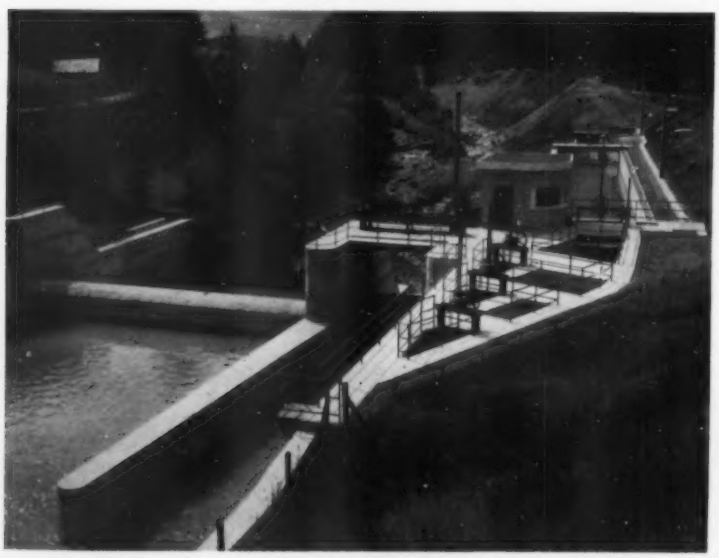


Fig. 25. Intake works on the Adda supplementing the supply to the Valgrosina tunnel

The Frodolfo branch tunnel is 3,443 m long and has an equivalent diameter of 2·18 m, a cross section of 3·94 m², and a gradient of 3·5 m/km. To reach the Zola adit communicating with the main tunnel this branch tunnel has to cross the Adda, and this is achieved by means of a syphon. The branch tunnel terminates in a vertical inlet shaft surmounted by a surge chamber, 1,100 m³ in capacity, which also receives water diverted from the Vallecetta mountain stream. The Vallecetta intake can divert 1 m³/sec and can pass a flood of 12 m³/sec; like the Massaniga intake, to be described in a moment, it has been designed to withstand the scouring action of snow and avalanches. The conduit from the intake to the Zola surge chamber is 335 m long and consists of a reinforced-concrete pipe 0·8 m in diameter.

The syphon proper measures 688 m horizontally and about 750 m in developed length. It is in five sections. The first, 25·18 m long and in steel piping 1·70 m in diameter, incorporates a vent pipe, a butterfly valve, which closes automatically in the event of excess water velocity, and an air-admission valve. The second section, which is 341·46 m long and 1·72 m in diameter, is built of "Bonna classic" pipes, which consist of a metal skin covered inside and out with reinforced concrete. The section is buried under an earth cover ranging up to 2 m deep, and has four vertical bends. The actual crossing of the Adda is effected by the third section, which consists of a steel pipe, 144·15 m long and 1·70 m in diameter, carried on a reinforced-concrete bridge; this pipe also passes below a roadway on each bank of the Adda. The bottom discharge for the syphon is located in this section. The fourth section is similar in construction to the second, but is 212·59 m long and has three vertical bends. The final section, in steel piping, connects with the Zola adit. It is 25 m long and incorporates an air-admission valve, a self-closing butterfly valve, a plug-type shut-off valve and a manhole.

The Massaniga stream intake, which withdraws 2 m³/sec and can pass a flood of 30 m³/sec, is an experimental installation embodying automatic gravel removal, and its performance is being studied from the standpoints of efficacy and reliability. As the intake is in a locality exposed to heavy snow and avalanches the weir has been specially shaped to resist the scouring action of the snow.

Each of the two other side intakes is designed to divert a flow

Fig. 26. Grosio discharge works, looking towards the tailrace tunnel. The channel on the left supplies Lovero station and the side spillway returns surplus water to the Adda

of 1 m³/sec and pass a flood of 10 m³/sec.

The outlet portal of the main tunnel has an invert level of 1,193·10 m and a crown level of 1,198·04 m. It can be closed by a sliding sluice gate when it is desired to pass water direct to the power station without its entering the reservoir. In this event the water is admitted to a bypass tunnel about 50 m long and 4·54 m in diameter. At the point where the bypass tunnel commences, a gooseneck-shaped gallery is taken off which acts as an overflow-type surge shaft.

As the maximum retention level of Valgrosina reservoir is 1,210 m the main tunnel outlet will be drowned when the water rises above 1,198 m. Many model tests have been carried out to determine the loss of flow and the maximum permissible pressure in the tunnel, and to study the precise hydraulic conditions obtaining, particularly with regard to air entrainment.

Valgrosina Reservoir and Dam

Valgrosina reservoir performs a vital function in rendering the operation of Grosio station largely independent of the discharge from Premadio—an essential condition because Grosio, as the largest station on the system, is used for frequency control. Furthermore, during the summer Cancano reservoir is closed for refilling and Premadio station is shut down, so that during this period Grosio station has to rely on storage and on waters other than the Premadio discharge.

We have already explained that numerous waters are collected in the supply tunnel other than the Premadio tailwater, but in addition, Valgrosina reservoir impounds the waters flowing in the Valgrosina and renders them available to Grosio station. This will make the Fusino reservoir and the old Roasco station obsolete.

In this connection account has to be taken of a future development in the Valgrosina (see Fig. 4) to make the utmost use of the waters of both branches of the Roasco—Roasco di Eita and Roasco di Sacco. A reservoir of 2 million m³ capacity is to be constructed at Pugnalto on the Roasco di Eita at a retention level of about 1,485 m, and the waters of the Roasco di Sacco will be diverted to it. This reservoir will feed a 35-MW station, to be known as Upper Roasco station, which will discharge to Valgrosina reservoir and will be of the pumped-storage type. During the summer this station will raise about 300,000 m³ to Pugnalto reservoir during the night for use during the day.

The capacity of Valgrosina reservoir was determined by the requirements of daily and weekly regulation. Daily regulation was calculated to need a capacity of about 520,000 m³ and weekly regulation 1,040,000 m³, and a combined capacity of 1,400,000 m³ was chosen. To this capacity can be added a further 250,000 m³, which represents the volume stored in the supply tunnel when drowned by the filling of the reservoir.

The location of the reservoir was virtually fixed by the level of the supply tunnel—itself determined by the level of the Premadio tailwater—and the selection of the dam site presented little or no alternative. The site leaves something to be desired, but the few possible alternatives would have presented much more serious constructional difficulties.

At the site selected the Roasco flows in a compara-

Fig. 27. A view inside the main section of the Valgrosina supply tunnel

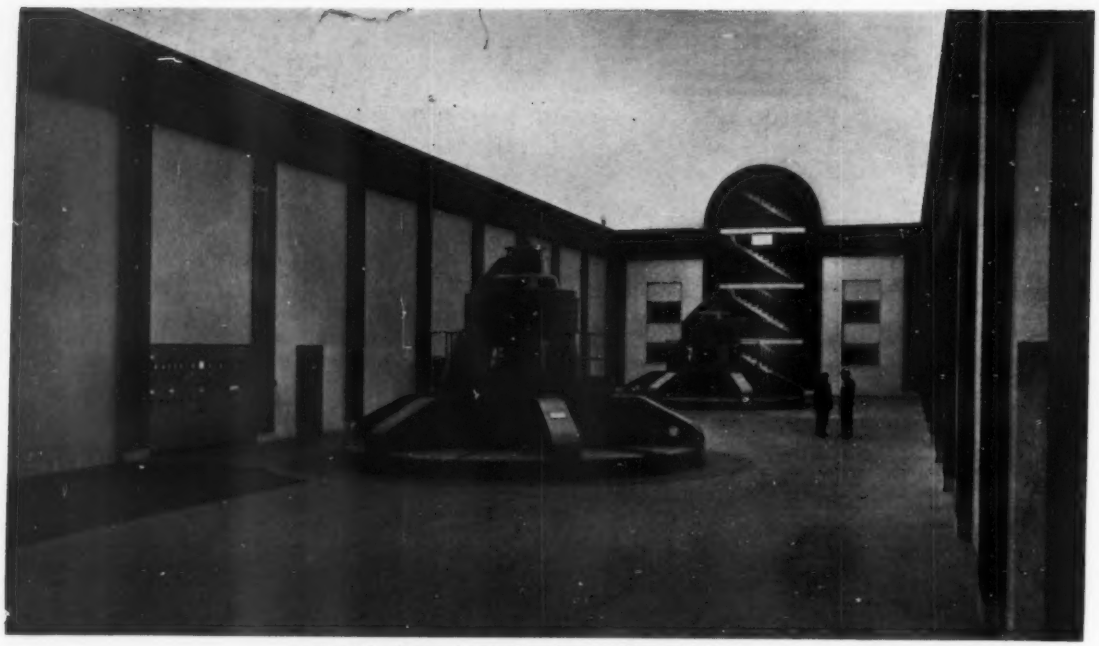


Fig. 28. Stage I of Grosio machine hall

tively wide U-shaped valley typical of glacial origin. The bedrock is a grey micaceous gneiss but it is heavily overlain by glacial moraine and detritus, particularly on the left bank. The river, however, has not only cleared away the moraine overburden in its bed, but has cut a deep channel in the bedrock. Any kind of arch dam would have been most unsuitable because, quite apart from the comparative width of the valley, the valley walls would not have afforded the necessary support, and the best form of construction was found to be a hollow buttress type.

An upstream elevation of the dam is given in Fig. 22. The dam is 286 m long and 4 m wide at crest, and is divided into 15 blocks ranging in height from 55 m over the river bed to 32 m on the left flank and 25 m on the right flank. The inclination of the upstream face is 0·13 and of the downstream face of 0·70. The crest is at an elevation of 1,212·50 m, giving a freeboard of 2·5 m at high water level. At the centre of the crest are two spillway openings, each controlled by a tainter gate 8 m wide by 3 m high, and in the base of the centre blocks are two scour sluices, 1 m in diameter, each protected by a sliding gate over the upstream mouth and controlled by two plug valves in series at the downstream end.

To divert the river preparatory to constructing the dam and to deviate the silt and gravel brought down by floods, a permanent cofferdam was built at the upstream end of the reservoir site to direct the flow into a tunnel, 812 m long and with a gradient of 4%, cut in the rock in the left bank. The lower part of this tunnel was subsequently enlarged to receive the bottom drainage sluice for the reservoir and also as the discharge channel for the gooseneck spillway already referred to in connection with the bypass tunnel. Above the junction with this spillway channel the tunnel has a cross section of 6·82 m² for a flow of 80 m³/sec, and below the junction the section is increased to 13 m² to handle a flow of 160 m³/sec. The tunnel discharges to the Roasco river bed about 250 m below the dam.

To enable the dam to be built, the moraine overburden, of course, had to be excavated to bedrock. Primary and secondary impervious screens were formed in the foundation rock by grouting, and the dam was also grouted to the foundation rock. When the dam was complete, the overburden was backfilled; that on the upstream side was compacted and was protected against wave action for a distance of about 100 m by porous concrete tiles (see Fig. 21).

On each side of the dam, where the natural ground surface rose above the dam crest, it was necessary to construct a concrete cut-off wall in the moraine overburden to a point at which the bedrock rose above the retention level. As the ground surface rises considerably above the parapet of the dam, each of these walls was constructed by driving a tunnel at parapet level into the side of the valley, continuing the line of the dam crest, and excavating a series of pits, 2·5 m wide and 8 m long, down to bedrock. After these pits had been filled with concrete, the intervening spaces were excavated and concreted, making a continuous wall. The left-hand cut-off wall extends 120 m into the hillside, and the right-hand wall 65 m.

The unstable character of the deposits along the left bank of the reservoir introduced the risk that the repeated filling and emptying would wash away parts of the bank and that the material so removed would diminish the capacity of the reservoir. The bank was therefore dressed to a slope of 1 : 3 over the zone affected by the water surface and to 1 : 1 above it, some 250,000 m³ of material being removed.

Pressure Tunnel and Surge Chamber

The pressure-tunnel intake is protected by a fixed bar screen and is closed by two sliding gates in series, each 3·10 m wide by 4·30 m high, which are operated by pressure-oil equipment housed in a rock chamber. The tunnel is 2,995 m long from the intake to the pen-

stock head-valves and dips at a gradient of 3·5 m/km except for the last 100 m where the gradient is increased to 10 m/km. It is of circular section, 5·44 m in diameter, and is designed to pass 80 m³/sec at a velocity of 3·44 m/sec under a head of 60 m.

At a distance of 2,880 m from the intake the tunnel bifurcates, the two limbs serving respectively the first stage (on the left) and the future second stage (on the right) of Grosio station (see Fig. 23).

Advantage has been taken of this bifurcation to construct a somewhat unusual form of surge chamber. Three vertical shafts, each 4·94 m in diameter, rise from the bifurcation, one located over the neck of the bifurcation and the others from the two limbs. The tops of these shafts are joined together by three straight lengths of tunnel, of horseshoe section 5·44 m wide and 6·20 m high, forming a triangular-shaped expansion chamber of 7,000 m³ capacity. The chamber is vented to atmosphere through the access gallery, 112 m long, and any air entrained in the pressure tunnel is relieved through an inclined shaft, 2·8 m in diameter, branching off from the vertical shaft above the neck of the bifurcation.

Towards their lower extremities the three vertical shafts are connected by a compensating chamber, also of 7,000 m³ capacity, but of circular cross section 4·94 m in diameter and disposed in the form of a B.

Each of the two limbs of the bifurcation is 96 m long and has a circular section 4·14 m in diameter and a gradient of 1% for the first 60 m, increasing thereafter to 2·5%.

Head-Valve Chamber and Penstock

Each limb of the bifurcation terminates in a valve chamber 14·8 m long, 10 m wide and 15·8 m high. In the chamber for the first stage are two 3·4-m butterfly valves in series, equipped with a bypass valve and succeeded by a float-operated air valve. The butterfly valves can be operated either by hand or by an oil servomotor, and closing can also be effected automatically by the occurrence of a water velocity 20–30% above normal. The valve chamber is served by a 26-ton crane.

The penstock is laid freely in an inclined tunnel, 862 m long and descending at a gradient of 85%. The tunnel is 5·80 m wide and 4·47 m high perpendicular to the inclined floor. The upper part of the penstock is of plain welded steel plate and is carried on concrete saddles; the lower part is of the hooped type and is carried on continuous rails mounted on low longitudinal walls. On the right-hand side of the penstock is the track for the service trolley, with stairs between the rails.

The penstock is designed for a maximum flow of 40 m³/sec and for a static head at the bottom of 615 m plus a surge pressure of 12%. It reduces progressively in diameter from 3·400 to 2·900 m, the corresponding water velocities ranging from 4·405 to 6·056 m/sec. The plate thickness ranges from 12 to 35 mm for the welded section and from 12 to 37 mm for the hooped section, the hoops ranging in cross section up to 100 by 48 mm. Anchor blocks are provided at the bends at the upper and lower extremities of the inclined penstock, which is further secured by five intermediate anchor blocks. There are no expansion joints. The lower horizontal portion of the penstock bifurcates to serve the two machines and is encased solidly in concrete.

The penstock tunnel was driven in an upward direction from three faces, opened up respectively from the

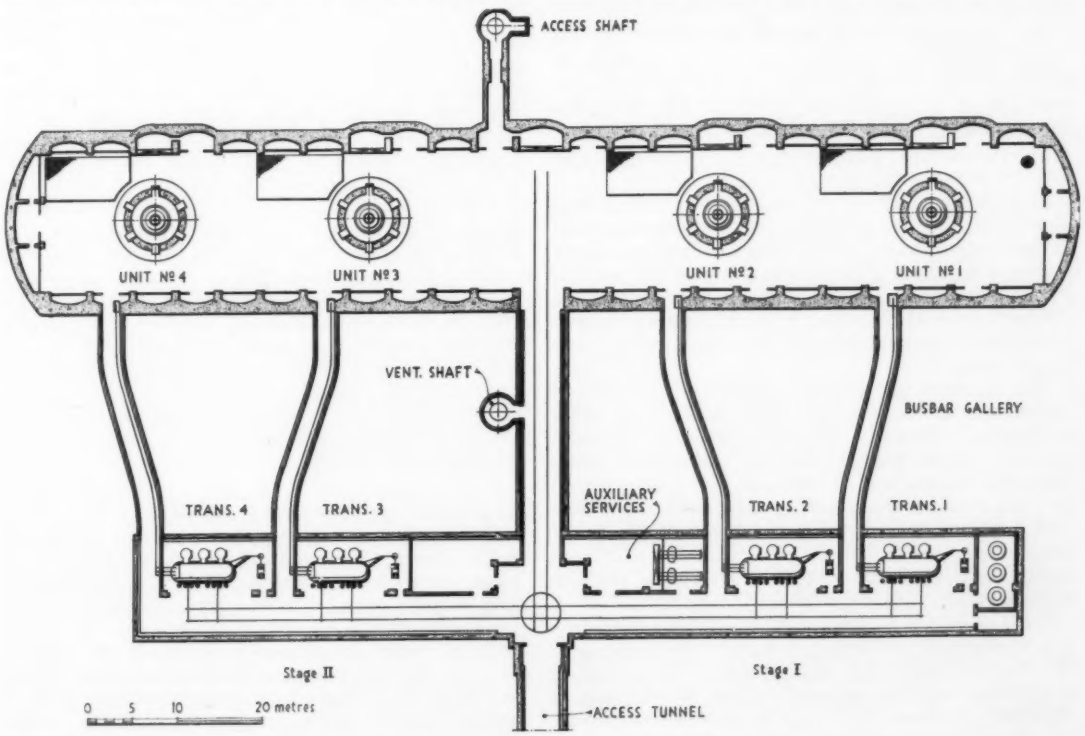


Fig. 29. Plan of Grosio underground power station

underground power station at a level of 611 m and from a lower and an upper adit at levels of 718 and 1,000 m. The upper adit is 90 m long, and the lower adit, which is 475 m long, also acts as the ventilation outlet for the power station, with which it is in communication through a vertical shaft about 106 m long. This adit also contains a fire-service reservoir and a smaller reservoir for drinking and sanitary water. Both of these reservoirs are replenished by underground springs that were tapped during excavation.

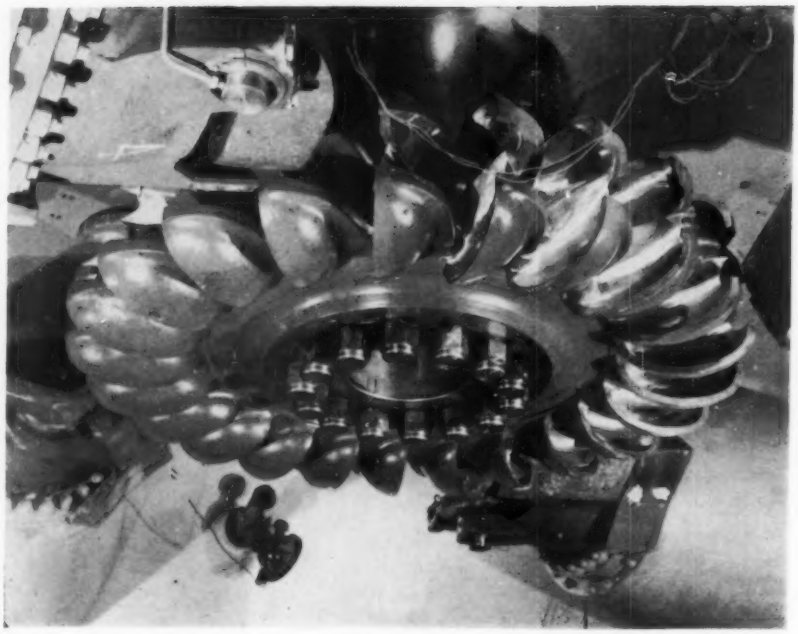


Fig. 30. One of the Franco Tosi vertical Pelton wheels

Underground Station

The underground station, seen in plan in Fig. 29, comprises a machine hall and a transformer hall arranged parallel to each other with a rock pillar 25 m thick between them. An access tunnel passes through the centre of the transformer hall and terminates at the centre of the machine hall. Four busbar galleries pass through the rock pillar to carry the busbars from the four generating sets to their respective transformers.

The gross dimensions of the machine hall are 120·80 by 19·40 by 33·10 m, measured to the inside of the primary lining, and the corresponding net dimensions are 114·20 by 15·60 by 30·95 m. The roof arch intrados rises 14·75 m above the machine-hall floor.

The transformer hall measures 103·10 by 11·00 by 10·15 m between the primary linings.

In both the machine hall and the transformer hall liberal use was made of Perfo rockbolts to secure the linings to the rockwalls and also to strengthen weak places in the rock. Fairly extensive grouting was required, particularly in the machine hall. One of the difficulties was the presence of aggressive waters, and to withstand their action ferro-pozzolan cement was largely used.

The entrance tunnel is 4 m wide by 5 m high; it commences in the vestibule of the control and office building and extends a distance of 586 m at a gradient of 2·2%. At the junction with the transformer hall a turntable enables the transformers to be transported on rails between the assembly area on the machine-hall floor and their respective cubicles. The 220-kV power cables are carried in the false ceiling of the entrance tunnel, and the control cables are led through a cable tunnel below the floor.

On one side of the section of access tunnel between the transformer and machine halls is the opening to the vertical ventilation shaft already mentioned in connection with the penstock tunnel. In an offset in this shaft at a level of 635 m is a reservoir for the cooling water for the machines and transformers, and the cooling-water pumps are located in a downward extension of the shaft below access-tunnel level. A connection from the roof of the machine hall joins the ventilation shaft at a level of 637 m.

Tailrace

The turbine discharge channels have been constructed both for the two machines in the present stage and for the two future machines constituting the second stage, and an emergency discharge channel has also been cut between the penstock tunnel and the second-stage turbine discharge channels. All four channels converge to a free-flow tailrace tunnel 1,163 m long, 7·20 m wide and 5·80 m high and falling at a gradient of 0·1%. The final 200 m of this tunnel runs near the surface in an alluvial deposit and was constructed by opencut, the concrete lining being cast and the trench then backfilled.

At the mouth of the tunnel, sliding gates control the entry of the Grosio tailwater into the basin feeding the supply tunnel to Lovero station, which is the next plant downstream on the main Adda watercourse. To dispose of the discharge when Lovero station is unable to accept it, a lateral spillway allows the surplus to enter a channel, 440 m long, which conducts it to the river (see Fig. 26).

Mechanical and Electrical Equipment

The two generating sets now in service are vertical Pelton machines, the shafts being in two sections and supported by a thrust bearing and two guide bearings. The running speed is 333 r.p.m. and the runaway speed 610 r.p.m.

Each turbine consists of a single wheel driven by four jets, the wheel being a stainless-steel integral casting weighing 17 tons. At a maximum head of 600 m and a discharge of 20·35 m³/sec the output is 107,135 kW, and at a minimum head of 565 m the corresponding figures are 19·74 m³/sec and 97,860 kW. The four

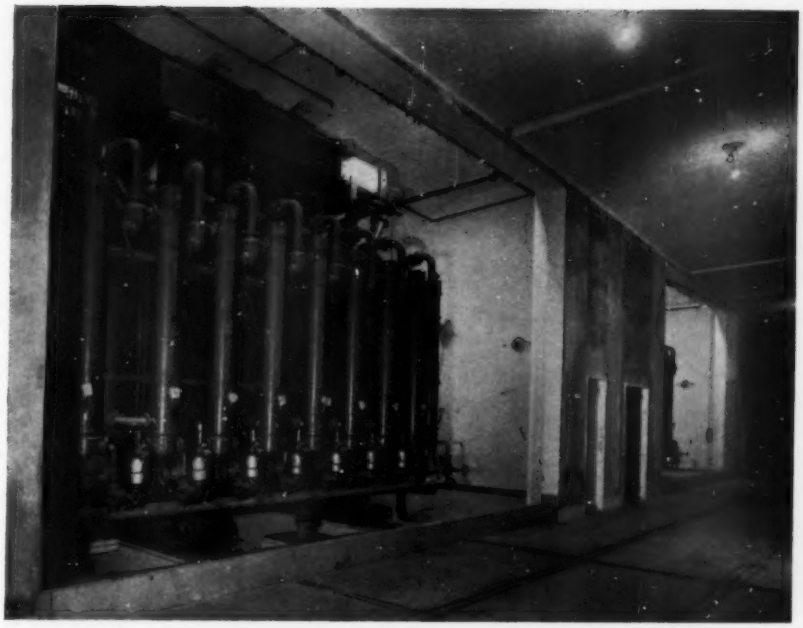


Fig. 31. T.I.B.B. transformers in the transformer hall

nozzles are equipped with the usual spears and deflectors, and water to all four nozzles is admitted through a rotary valve. Upstream of this valve is a venturi section to enable the discharge to be measured at any moment.

The alternator is ventilated on closed circuit, and generates at 16 kV 3 ph 50 c.p.s.

Each alternator is connected to its own transformer, which is a 115-MVA three-phase forced-oil-cooled unit stepping up to 240 kV. A third unit is available as a spare. The cables leading to the outdoor switchyard are of the single-core oil-filled type.

The machine hall is served by two 185-ton cranes.

As already mentioned, the surface control and administrative building is situated at the entrance to the access tunnel. It contains the control room, circuit-breaker maintenance shop, a 23-kV substation for the local supply system, and the necessary offices. Alongside this building is the outdoor switchyard, which is 146 m long and 90 m wide.

The switchyard is of the double-busbar type, and is equipped with minimum-oil circuit breakers of 4,000-MVA rupturing capacity to control the output from the generating sets, and with 5,000-MVA air-blast circuit breakers for the transmission lines. The power cables from the main transformers are brought to their appropriate outlets by underground cable galleries, whereas the control cables and compressed-air service pipes are conveyed in covered trenches.

The 220-kV overhead lines comprise (a) a new double-circuit line to North Milan, (b) a link with the existing Grosotto station, (c) a single-circuit line to South Milan which is already supplied by Premadio station, (d) a single-circuit connection with Premadio, and (e) a spare panel. The 23-kV local network, fed from the other A.E.M. stations, through two 200-kVA transformers, supplies the external services at 220 V, and is also supplied through two 700-kVA transformers housed in the first cubicle of stage one of the transformer hall. In the corresponding cubicle on the second-stage side are the station batteries.

Allocation of Costs

Of the total cost of the Grosio development, excluding the transmission line to Milan, civil engineering accounted for 85% and mechanical and electrical equipment 15%. On the civil-engineering side the major items were the Premadio-Valgrosina supply tunnel, which accounted for 37·4%, Valgrosina dam 13%, and the underground power station 6·5%. Of the mechanical and electrical equipment the generating sets (stage one) represented 5·9% and the penstock 3·5%.

Consultants, Contractors and Manufacturers

The Grosio development was designed by the technical staff of Azienda Elettrica Municipale di Milano except for Valgrosina dam, which was designed by Ing. Prof. Felice Contessini. The architect responsible for the surface building was Ladislao Kovacs, of Milan. The following is a list of the principal contractors and manufacturers concerned:—

CIVIL ENGINEERING

Adda and Viola Intakes
Giudicariese Costruzioni Idroelettriche, Milan.

Frodolfo Intake and Branch Tunnel
Geom. Leone Collini, Milan.

Premadio-Valgrosina Supply Tunnel
Giudicariese Costruzioni Idroelettriche, Milan.
Immobili Bonifiche Appalti, S.p.A., Milan.
Ingg. Lino & Ito del Favero, Trento.
Ing. E. Recchi, Turin.

Zola Syphon
Geom. Luigi Ferrari, Tirano.

Valgrosina Dam and Reservoir
Ing. Lodigiani, S.p.A., Milan.

Roasco de Sacco Diversion
Ing. Lodigiani, S.p.A., Milan.
Geom. Guerrino Brunella, Sondrio.

Pressure Tunnel, Surge Chamber and Valve Chamber
Ing. E. Recchi, Turin.

Penstock Tunnel, Power Station, Access Tunnel, Surface Building and Switchyard
Gandini & Vandoni, S.p.A., Milan.

Tailrace
Astaldi, Rome.

Fig. 32. Grosio control room, located in the surface building

SUBCONTRACTORS FOR GROUTING

Supply Tunnel
Luigi Notari, Segrate, Milan.
A. Bertini, Milan.
Iniesond, s.r.l., Belluno.

Power Station
Soc. ELSE (Edifizia-Lavori Sottosuolo-Estrusioni), Milan.

Valgrosina Dam
Ing. Giovanni Rodio & Co., Milan.

MECHANICAL AND ELECTRICAL EQUIPMENT

Main Intake Gates
Soc. Alessandro Calzoni, Bologna.

Subsidiary Gates
Soc. OMGD (Officine Meccaniche Galimberti e Donato), Battaglia Terme, Padua.
Soc. Lenzi, Trento.

Valgrosina Dam and Reservoir Gates and Valves
Soc. Alessandro Calzoni, Bologna.

Zola Syphon, Metal Pipes
Soc. Alessandro Calzoni, Bologna.

Reinforced-Concrete pipes
Soc. Tubi Bonna, Milan.

Penstock and Butterfly Valves
Soc. COFOR, Milan.
Soc. Terni, Milan.

Turbines and Valves
Soc. Franco Tosi, Legnano.

Generators and Main Transformers
Tecn. Ital. Brown Boveri, Milan.

Auxiliary Transformers
Breda, Milan.

Cranes
Soc. Gentili & Brighi, Milan.

Pumps
Pellizzari & Figli, Milan.
Worthington, Milan.

Control-Room Equipment
Tecn. Ital. Brown Boveri, Milan.

Control-Room Equipment (auxiliaries)
SACE (S.p.A. Costruzioni Elettromeccaniche), Bergamo.

220-kV Cables
Pirelli, Milan.

Circuit Breakers
Magrini, S.p.A., Milan.

Isolators
MIVA (Manifatture Isolatori Vetro-Acqui), Milan.

Switchyard Steelwork
Società Anonima Elettrificazione, S.p.A., Milan.

Acknowledgments

These articles on the Valtellina development are published by kind permission of Azienda Elettrica Municipale di Milano and we are greatly indebted to Dott. Ing. Eugenio Barioli, Director of Construction, for his collaboration in their preparation. In addition to the copious material placed at our disposal by Dr. Barioli, much interesting information about Cancano dam was obtained from articles contributed to *L'Energia Elettrica* by Dott. Ing. Eugenio Barioli and by Prof. Felice Contessini and Prof. Guido Oberti. Some of the details about the Grosio development were obtained from an article contributed to *L'Impresa Pubblica* by Franco Lionetti.

Welded Tubular Shafts for Vertical Water Turbines

The author describes Russian proposals for producing turbine shafts by welding, and presents and compares design calculations by three alternative methods

By GUNNAR ENGLESSON*

IN the manufacture of water turbines, the tendency is nowadays towards greater and greater outputs per unit, which leads to shaft designs with large diameters. The size of a forged shaft, however, is limited by the capacity of the steelworks with regard to size of ingots, hammers and crane equipment. So far this limit has not yet been reached in Western Europe, but in the Soviet Union this has been the case, where it has been decided for the Bratsk plant† to use welded shafts in the shape of a thin-walled cylinder with welded longitudinal joints and united to the flanges by circumferential welded joints. This deviation from the conventional forged shaft is a noteworthy and interesting design novelty.

The introduction of welded joints between blades, hub and rim for Francis runners has secured many advantages, and there is no reason why welded shafts also should not be manufactured, and a valuable saving in costs obtained.

The decision to introduce welded shafts was preceded by extensive technical-economical analysis and research work described in Russian literature[1] by Bronovskij, Gamse, and Goldscher. Furthermore, Bugov has treated different methods for computing the stresses in flange connections of thin-walled shafts.

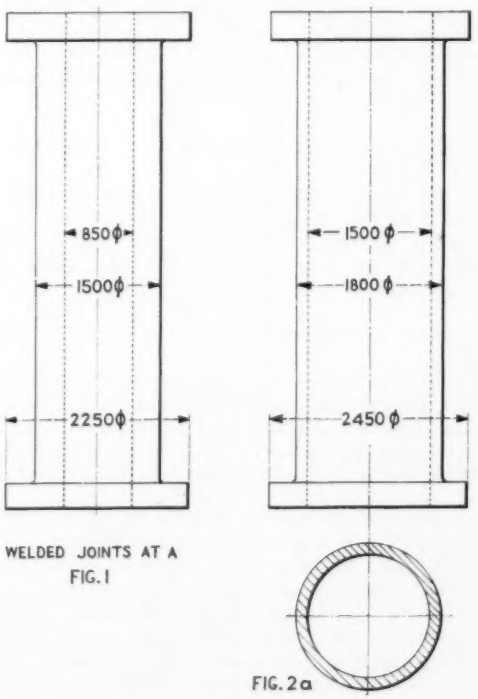
It was the development of the electro-slag-welding method at the Paton Institute for electro-welding in Kiev[2] which made welded turbine shafts a practical proposition. In addition to good welding economy the electro-slag-welding process is very adaptable to shafts. The following conditions must be fulfilled:

1. The wall thickness must be at least 40 mm.
2. The joint must be accessible along its whole length for the welding machine, at least from one side.
3. It must be possible to weld the joint right through and without interruption.
4. By turning the piece to be welded, it must be possible to bring the joint into the vertical position.

Investigations in the Soviet Union

As early as 1952, at the project stage of the Kuibyshev turbines, the use of welded shafts was under consideration, but the electro-slag-welding method was

* Trollhättan, Swed n.
† Data for the installation: H=96 m, P=224 MW, n=125 r.p.m., D=5·5 m.



WELDED JOINTS AT A
FIG. 1

FIG. 2a

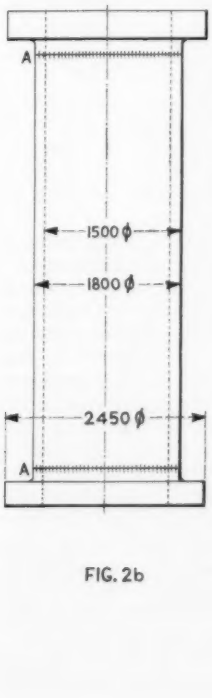


FIG. 2b

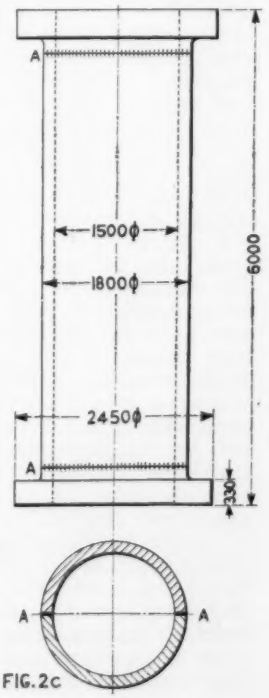


FIG. 2c

TABLE I

Type of shaft	Shaft diameter	Material	Net weight	Steel consumption	Utilisation factor of the steel	Total production cost	I	W_p
	mm		tons	tons		roubles	cm^4	cm^3
Forged shaft of conventional design. Fig. 1.	1,500/850	Wrought iron	64·0	223·0	0·29	550,000	$22{\cdot}29 \times 10^6$	600,000
Forged shaft with enlarged diameter. Fig. 2a.	1,800/1,500	Wrought iron	43·7	200·0	0·22	500,000	$26{\cdot}68 \times 10^6$	600,000
Welded shaft with forged tube. Circumferential joints against the flanges. Fig. 2b.	1,800/1,500	Tube of wrought iron. Flanges of cast steel.	43·7	132·0	0·33	353,000	$26{\cdot}68 \times 10^6$	600,000
Shaft with welded tube. Circumferential joints against the flanges. Fig. 2c.	1,800/1,500	Tube of welded steel plates. Flanges of cast steel.	43·7	102·0	0·43	265,000	$26{\cdot}68 \times 10^6$	600,000
Thin-walled shaft with forged tube. Circumferential joints against the flanges. Fig. 3a.	2,100/1,900	Tube of wrought iron. Flanges of cast steel.	38·2	140·0	0·27	366,000	$31{\cdot}5 \times 10^6$	600,000
Thin-walled shaft with welded tube. Circumferential joints against the flanges. Fig. 3b.	2,100/1,900	Tube of welded steel plate. Flanges of cast steel.	38·2	90.0	0·43	237,000	$31{\cdot}5 \times 10^6$	600,000

not used in industrial production until 1951 in the Soviet Union, and the lack of sufficient experience at that time prevented this idea from being carried into execution.

In order to forge these increasingly large shafts heavy ingots are required, as well as powerful hammers and crane equipment with great lifting capacity. To produce one of the shafts for Kuibyshev an ingot weight was required nearly approaching the limit of capacity of the steelworks.

By changing over from forged to welded shafts, a great deal of the foregoing difficulties will be removed. The steel consumption will be considerably less and the machining costs lower. By increasing the diameter and using a thin shaft wall made of rolled-steel plates, good mechanical properties of the material in the whole section will be achieved, and it will be possible to increase the working stresses compared with those permissible in forged shafts. For the Bratsk installation two fundamentally different designs of welded shafts were investigated. In the first design the shaft body was made as a forged tube, whereas in the second two bent steel-plate mantles joined together by welding formed the shaft body. For both of these designs it will be possible to use either cast-steel or forged-steel flanges. The uniting of the flanges to the shaft body is carried out by circumferential welded joints, all the joints being electro-slag welded.

As no experience was available in the welding of large turbine shafts a tabular summary was worked out in order to give guiding principles. In Table I some of the most important items are extracted, and accompanied by the Moment of Inertia I and the polar Section Modulus W_p. The various shaft designs are shown in Figs. 1–3.

SHAFT OF CONVENTIONAL TYPE, FORGED INTEGRALLY. DIAMETER 1,500 MM. FIG. 1

This type of shaft has only been studied as forged; the fact is that this design is not at all fit for welding. As can be seen from the Table, this shaft is the heaviest, with an ingot weight of 223 tons, which is nearly the limit for the steelworks.

SHAFT WITH A DIAMETER OF 1,800 MM. FIGS. 2a, 2b, AND 2c

Compared with the conventional design according to Fig. 1, the shaft integrally forged and with enlarged diameter, shown in Fig. 2a, will be more economical, but because of the amount of material machined off, the utilisation factor of the steel will be somewhat less.

To forge the tube for the shaft shown in Fig. 2b, an ingot weight of 105 tons will be needed.

A shaft with the tube made of two bent mantle plates with longitudinal joints is shown in Fig. 2c. The rolled-steel plates have a wall thickness of 180–200 mm before machining. Compared with a forged tube the material will be much better utilised. For a forged tube a machining allowance of 50 mm on the

outer diameter and 75–80 mm on the inner diameter will be required, but for the production of a tube made of rolled-steel plates with a finished wall thickness of 150 mm an allowance of only 25 mm on the surface is needed, corresponding to a total plate thickness of 200 mm.

SHAFT WITH A DIAMETER OF 2,100 MM. FIGS. 3a AND 3b

The increase in weight of the ingot for the forged tube shown in Fig. 3a compared with the corresponding ingot weight for the 1,800 mm shaft according to Fig. 2b will be nearly 10% and the utilisation factor will be correspondingly smaller.

From the analysis worked out in Table I it can be concluded that the design according to Fig. 3b gives the smallest steel consumption and the best economy. The costs for machining the shaft will also be comparatively low; for a finished wall thickness of 100 mm a plate thickness of only 110 mm will be needed, or a total machining allowance of 10 mm.

The flexural rigidity against bending will be about 40% higher with a welded tubular shaft having a diameter of 2,100 mm than with one having a diameter of 1,500 mm. The critical speed of shafts having equal lengths is proportional to the square root of the Moment of Inertia I. The welded-tube shaft with a diameter of 2,100 mm will therefore give a critical speed about 20% higher than the corresponding forged shaft. The critical speed increases also somewhat because the mass of the tubular shaft is only 60% of the mass of the forged shaft.

Computation of Stresses in Thin-Walled Shafts

The tensile stress in a forged thick-walled shaft produced by the axial load will be comparatively low. This is also the case with the radial bending stress in the flange, which can be computed by assuming the flange ring built in at the shaft wall and at the bolt circle. In comparison with a forged shaft the tubular shaft has a smaller area of cross section, and consequently the tensile stress will be greater. The junction surface between a flange connected to a thin wall will also be subjected to bending stresses, which, combined with the shearing stress, reduce the allowable torque.

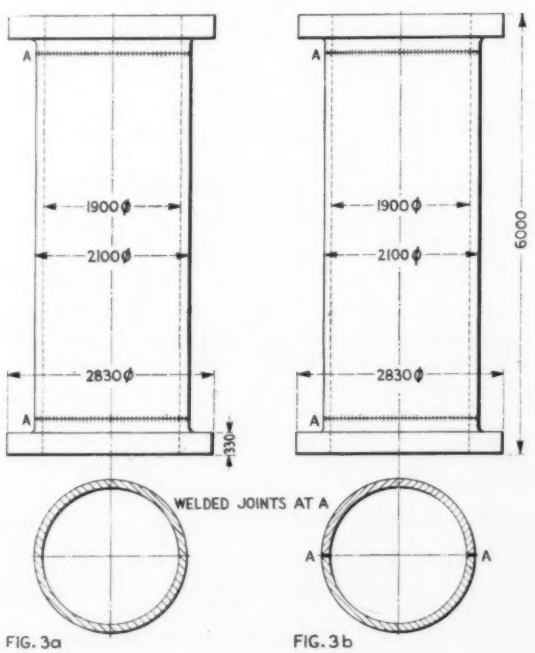


FIG. 3a FIG. 3b

In order to obtain equal torques for the two shafts it will therefore be necessary either to give the tubular shaft such dimensions that the polar Section Modulus will be greater than for the forged shaft or to use a steel with better elastic properties.

The radial bending moment in a flange ring connected to a thin wall is greater than when the wall is thick, due to its weaker flange connection. In some cases it will therefore be necessary to make a thicker flange for a thin-walled welded shaft than for a forged shaft.

The determination of the dimensions of vertical shafts is made with regard to shearing and tensile stresses. The combined stress is calculated as a comparison stress at plane-stress conditions according to the deviation work hypothesis:

$$\sigma_I = \sqrt{\sigma_1^2 + 3\tau^2} \qquad \ldots (1)$$

where σ_1 is the maximum tensile stress occurring at the outside of the shaft wall and τ is the maximum shearing stress.

$$\text{The ratio } S = \frac{\text{Lower yield point}}{\text{Comparison stress}} = \frac{\sigma_s}{\sigma_I} \qquad \ldots (2)$$

must in accordance with common rules attain a minimum of 4.

Nomenclature

P = Axial shaft load in kg.
P_R = Compressive force outside of the bolt circle in kg.
P_s = Bolt load in kg.
Q_o = Shearing force in kg per unit length at the middle radius of the shaft wall.
I = Moment of Inertia of shaft cross section in cm⁴.
$W_p = \frac{2I}{r_y}$ = Polar Section Modulus of shaft cross section in cm³.
M_v = Torque moment on shaft in kg cm.
M_o = Bending moment in kg cm per unit length of the middle radius of the shaft wall.
r_y = Outer radius of shaft in cm.
r_o = Inner radius of the flange in cm.
r_1 = Outer radius of the flange in cm.
r_2 = Radius of bolt circle in cm.
r = Middle radius of the shaft wall in cm.
$\alpha = \frac{r_1}{r_o}$
h = Flange thickness in cm.
s = Wall thickness in cm.
$\beta = \frac{1{,}285}{\sqrt{s \times r}}$ = Tube coefficient in cm⁻¹.
$m = 1 + \frac{\beta h}{2}$
n = Number of bolts.
d = Bolt diameter in cm.
F = Bolt area in cm².
K_1, K_2, K_3, K_4 = Calculation factors.
k = Reduction factor for the flange section ***B-B***.
σ_o = Bending stress in section ***A-A*** in kg/cm².
σ_a = Tensile stress in section ***A-A*** in kg/cm².
σ_1 = Maximum tensile stress in section ***A-A*** in kg/cm².
σ_2 = Radial bending stress in section ***B-B*** in kg/cm².
σ_d = Tensile stress in the sectional area at bottom of bolt thread in kg/cm².
ϕ = Angle of rotation of flange.

In order to calculate the bending stress at the section of the junction of wall and flange (***A-A*** in Fig. 4a), two internationally known methods are often

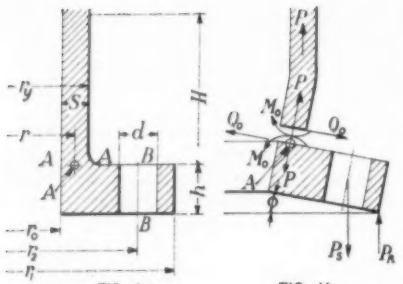


FIG. 4a

FIG. 4b

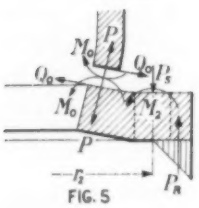


FIG. 5

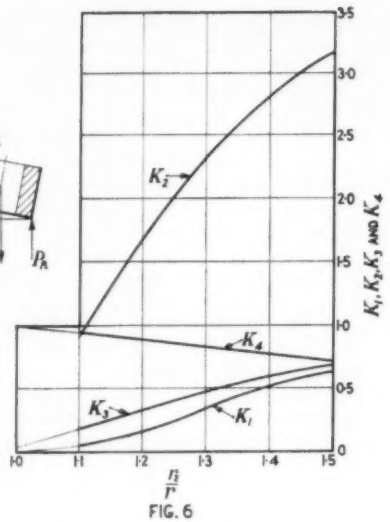


FIG. 6

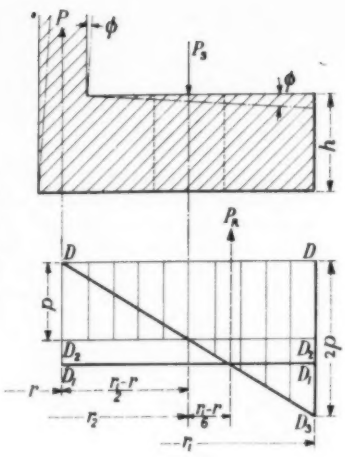


FIG. 7

used: (a) Waters and Taylor[3], and (b) Timoshenko[4]. The equations of the first-mentioned method are rather complicated and special charts are required for the calculations. In "Modern Flange Design" such assisting charts make design convenient.

The approximate formula derived by Timoshenko has the following form:

$$M_o = \frac{P(r_2 - r)}{2\pi r} \cdot \frac{1}{1 + \frac{\beta h}{2} + \frac{1}{2}\left(\frac{h}{s}\right)^3 \log_e \alpha} \qquad \ldots (3)$$

The equations of these two methods, however, can be applied only to flanges that are free to deflect under the action of forces, and not for flanges in contact outside the bolt circle; the stresses for turbine shaft flanges as derived from these equations would be too great. Bugov, by assuming different bolt pulls, has developed two calculation methods:

I. The bolts are assumed to be pulled up slightly, and the angle of rotation of the flange will depend on the extension of the bolts.

II. The bolts are assumed to be tightened to a pull corresponding to a stress of 1,000–1,200 kg/cm² in the sectional area at the bottom of the thread. The flange can therefore be calculated as built in at the bolt circle.

The assumption of very slightly preloaded bolts is not in full accordance with actual conditions, as the bolt force in shaft flanges is always checked by measuring the bolt extension. It would therefore be more appropriate to use method II in calculating the bending stresses in the junction between the wall and the flanges. The bending stresses calculated in accordance with method I will be much greater than with method II and represents really the maximum stresses arising under very unfavourable conditions.

By giving the flange certain dimensions, however, in relation to size and position of the bolts, a substantial reduction in stress in the most highly strained section *A-A* can be obtained. This calculation method will hereinafter be called method III, and is based on the joint pressure between the flanges. It was originally developed by Stodola for use with steam turbines to estimate the distortion of the turbine housing by the twisting of the flanges.

The formulae presented herein are based on the derivation of equations by the Swedish Pressure Vessel Committee[5] for use when designing integral flanges that are free to deflect.

Calculation Method I

Assuming the flange rotates through an angle ϕ without distortion under the action of the force P to a position as shown in Fig. 4b, with the moments M_o and $\frac{Q_o h}{2}$ acting at the section *A-A*, the moment of twist on the flange ring will be obtained from the equation:

$$M_t = \frac{P(r_1 - r)}{2\pi r} - M_o - \frac{Q_o h}{2} - \frac{M_B}{2\pi r} = \frac{E h^3 \log_e \alpha}{12 r} \qquad \ldots (4)$$

Where E = Modulus of Elasticity of the material. A bolt load of P_s kg per bolt gives the total bolt moment:

$$M_B = n P_s (r_1 - r_2) \qquad \ldots (5)$$

With a bolt length of 2 h, P_s becomes

$$P_s = \sigma F = \frac{E F \Delta h}{h} = \frac{E(r_1 - r_2) F \phi}{h} \qquad \ldots (6)$$

From equations (5) and (6)

$$M_B = \frac{n E F (r_1 - r_2)^2 \phi}{h} \qquad \ldots (7)$$

Inserting equation (7) in equation (4):

$$\frac{P(r_1 - r)}{2\pi r} - M_o - \frac{Q_o h}{2} - \frac{n E F (r_1 - r_2)^2 \phi}{2\pi r h} = \frac{E h^3 \log_e \alpha \phi}{12 r} \qquad \ldots (8)$$

Due to the rotation of the flange through the angle ϕ, the circumference of the ring and the wall expands and the point *A* is displaced radially a distance

$$\delta = \frac{h\phi}{2} \qquad \ldots (9)$$

For a long tube under the action of moments and forces at the boundary surface the following equation holds true (with a Poisson's ratio of 0·3)

$$\delta = (Q_o - \beta M_o) \frac{10{\cdot}9}{2\beta^3 E s^3} = \frac{h\beta}{2} \qquad \ldots (10)$$

From equation (10):

$$Q_o = \beta_o \left(M_o + \frac{\beta^2 E s^3 h \phi}{10{\cdot}9} \right) \qquad \ldots (11)$$

And the angle of rotation of the shaft wall is:

$$\phi=\frac{10{\cdot}9}{2\beta^2 E s^3}(M_o 2\beta - Q_o) \quad \ldots (12)$$

If Q_o according to equation (11) is inserted in equation (12) the following equation for the wall angle will be obtained

$$\phi=\frac{10{\cdot}9\,M_o}{2\beta E s^3\left(1+\frac{\beta h}{2}\right)}=\frac{5{\cdot}45\,M_o}{\beta m E s^3} \quad \ldots (13)$$

$$\text{where } m=\left(1+\frac{\beta h}{2}\right) \quad \ldots (14)$$

By inserting the magnitude of the wall angle ϕ according to equation (13) in equation (11), Q_o expressed in M_o will be obtained

$$Q_o=\beta M_o\left(1+\frac{\beta h}{2m}\right) \quad \ldots (15)$$

With Q_o inserted in equation (8) and the angle for the flange ring equal to the angle for the wall according to equation (13), the final equation for M_o can be represented in the following form:

$$M_o=\frac{P(r_1-r)}{2\pi r}\cdot\frac{m}{m^2+(m-1)^2+\frac{1}{2{\cdot}2}\left(\frac{h}{s}\right)^3\frac{\log_e\alpha}{r\beta}+\frac{5{\cdot}45\,n F (r_1-r_2)^2}{2\pi r h\beta s^3}} \quad \ldots (16)$$

Owing to the fact that the bolts for turbine shaft flanges are generally fitted, the twisting moment M_t will be slightly decreased due to the resisting moment from the "built-in" bolts. In order not to complicate the equation still more, this moment has been neglected. An investigation shows that M_o decreases about 5–10%, if the resisting moment from the bending of the bolts through the angle ϕ is taken into account.

Maximum Tensile Stress in the Section A-A

The bending stress in the section *A-A* will be

$$\sigma_o=\pm\frac{6\,M_o}{s^2} \quad \ldots (17)$$

The tensile stress due to the force P from the equation

$$\sigma_a=\frac{P}{2\pi r s} \quad \ldots (18)$$

The maximum tensile stress in the section *A-A* will thus be:

$\sigma_1=\sigma_o+\sigma_a$ at the outer surface of the shaft ... (19)

On a distance of $H=1{\cdot}56\sqrt{s r}$ from the upper edge of the flange, the influence of the moment M_o will be practically negligible. At that distance only the tensile stress σ_a remains.

Bending Moment in the Flange at the Bolt Circle, Section B-B

Inserting according to equation (13) in equation (7), the bending moment M_2, referred to the radius of the bolt circle, will be obtained from the equation:

$$M_2=\frac{5{\cdot}45\,m_o(r_1-r_2)^2 F n}{2\pi r_2\beta m s^3 h}-\frac{P(r_1-r_2)}{2\pi r_2} \quad \ldots (20)$$

With a reduction factor $k=1-\frac{n d}{2\pi r_2}$ for the section *B-B*, weakened by the bolt holes, the bending stress in this section will be obtained from

$$\sigma_2=\frac{6\,M_2}{h^2 k} \quad \ldots (21)$$

CALCULATION METHOD II

The application of this method depends on the assumption that the bolt pull is sufficiently great not to open up the joint at the bolt circle, i.e., the joint pressure exerted on the loaded flange must not be less than 0 kg/cm² at the bolt circle. The part of the flange inside the bolt circle will deflect under the action of the load and is calculated as a circular plate built in at the bolt circle. At the inner edge the forces and moments act as shown in Fig. 5. The part of the flange outside the bolt circle is assumed not to rotate.

The load P will produce an angle of rotation of the inner edge amounting to

$$\phi_1=\frac{K_1 P r_2}{2\pi E h^3} \quad \ldots (22)$$

The moment $M_b=M_o+\frac{Q_o h}{2}$ will produce in the opposite direction at the inner edge an angle of rotation equal to

$$\phi_2=\frac{K_2 M_b r_2}{E h^3} \quad \ldots (23)$$

The angle of rotation of the shaft wall will thus be

$$\phi=\phi_1-\phi_2=\frac{K_1 P r_2}{2\pi E h^3}-\frac{K_2 M_b r_2}{E h^3} \quad \ldots (24)$$

With ϕ according to equation (13) inserted in equation (24) and $M_b=M_o+\frac{Q_o h}{2}$.

Where $Q=M_o\left(1+\frac{\beta h}{2m}\right)$ from equation (15) the formula for M_o becomes

$$M_o=\frac{K_1 P}{2\pi}\cdot\frac{m}{K_2[m^2+(m-1)^2]+\frac{5{\cdot}45}{\beta r_2}\left(\frac{h}{s}\right)^3} \quad \ldots (25)$$

The values of the factors K_1 and K_2 in relation to $\frac{r_2}{r}$ can be obtained from Fig. 6.

Bending Moment in the Flange at the Bolt Circle, Section B-B

This can be obtained from

$$M_2=\frac{K_3 P}{4\pi}-K_4 M_b$$

With $M_b=M_o+\frac{Q_o h}{2}$ and $Q_o=\beta M_o\left(1+\frac{\beta h}{2 m}\right)$ from equation (15) the bending moment becomes

$$M_2=K_3\frac{P}{4\pi}-K_4 M_o\left[1+\frac{\beta h}{2}\left(1+\frac{\beta h}{2m}\right)\right] \quad \ldots (26)$$

The factors K_3 and K_4 to be obtained from Fig. 6 for different ratios $\frac{r_2}{r}$.

CALCULATION METHOD III

The bolts are placed in the middle of the flange width r_1-r as shown in Fig. 7. When the bolts are pulled up, the flange is compressed and produces in the joint surface approximately a uniform pressure $D-D_1$. Under the action of the load P the bolts extend and the mean pressure diminishes to $D\text{-}D_2=p$ kg/cm². Due to the bending moment $P(r_2-r)$ the flange rotates through the angle ϕ and the joint pressure increases at the outer edge and decreases at the inner edge. In order to get contact over the whole surface, it is assumed that the pressure diminishes to

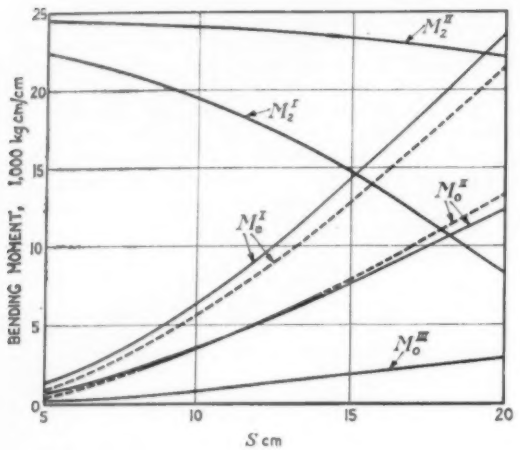


FIG. 8

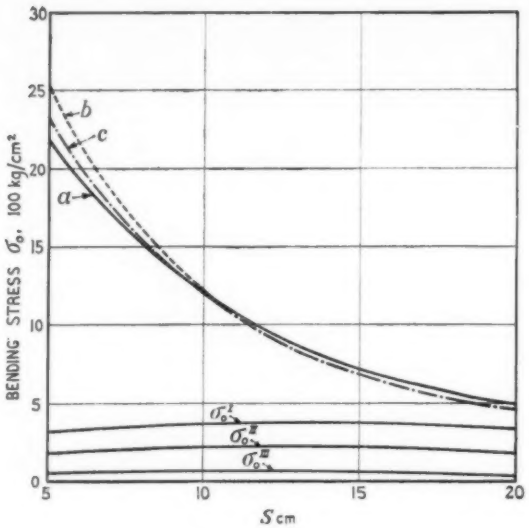


FIG. 9

zero at the inner edge. The pressure at the outer edge will then be equal to the double pressure p at linear pressure distribution. The resulting compressive force outside of the bolt circle acts then with a lever arm $\frac{r_1 - r}{6}$ from the bolt centre. $\frac{P(r_1 - r)}{2} = \frac{P_R(r_1 - r)}{6}$ gives $P_R = 3P$ and the bolt load becomes $P_s = P_R + P = 4P$, i.e., a bolt load four times the tensile force in the shaft wall. Because of the assumed linear pressure distribution the joint pressure $p = D_2 - D_3$ can be evaluated as a beam with the width b and the height a. With a radial moment of M_R the following expression for the pressure will be obtained

$$p = \frac{6 M_R}{b a^2} \qquad \ldots (27)$$

With the unit compression of the flange proportional to the flange thickness h follows

$$p = \frac{\Delta h E}{h} \qquad \ldots (28)$$

The angle of rotation of the flange is:

$$\phi = \frac{\Delta h}{a/2} \qquad \ldots (29)$$

The Moment of Inertia $I = \frac{b a^3}{12}$ introduced gives

$$\phi = \frac{M_R h}{I E} \qquad \ldots (30)$$

With the Moment of Inertia $I = \frac{(r_1 - r)^3}{12} \frac{r_2}{r}$ of the joint surface inserted in equation (30) the reactive moment of the flange will be obtained from:

$$M_R = \phi \frac{(r_1 - r)^3}{12 h} \frac{r_2 E}{r} \qquad \ldots (31)$$

The moment of twist on the flange ring from the equation:

$$M_t = \frac{P(r_2 - r)}{2 \pi r} - M_o - \frac{Q_o h}{2} - \frac{\phi (r_1 - r)^3}{12 h} \frac{r_2 E}{r} = \frac{E h^3 \log_e \alpha \phi}{12 r} \qquad \ldots (32)$$

In the same way as described under Method I, the bending moment at the junction between the flange ring and the shaft wall, section A-A, will be obtained from:

$$M_o = \frac{P(r_2 - r)}{2 \pi r} \Big/ \frac{m}{m^2 + (m-1)^2 + \frac{1}{2 \cdot 2}\left(\frac{h}{s}\right)^3 \frac{\log_e \alpha}{r \beta} + \frac{(r_1 - r)^3 r_2}{2 \cdot 2 h \beta s^3 r}} \qquad \ldots (33)$$

Bending Moment in the Flange at the Bolt Circle, Section B-B

With ϕ calculated according to equation (13) inserted in equation (31), the bending moment at section B-B per unit length at the bolt circle will be

$$M_2 = \frac{M_o (r_1 - r)^3}{2 \cdot 2 \beta m s^3 h} \qquad \ldots (34)$$

Comparison with Bugov's Methods I and II

In order to study how moments and stresses change at varying wall thickness s and constant flange thickness h, these are computed for the same axial load $P = 900$ tons. The computations have been based on the following selected dimensions of the flange and the shaft $r_1 = 140$ cm, $r_2 = 125$ cm, $r_a = r_o + s = 105$ cm, $h = 20$ cm, number of bolts $n = 20$, bolt diameter $d = 16{\cdot}5$ cm (M 160 × 6). The results of these calculations are shown graphically in Fig. 8. The bending moment at the section A-A increases with increasing wall thickness, whereas the radial moment in the flange at the section B-B decreases. As a comparison also the curves obtained from Bugov's formulae have been plotted (dotted lines).

Practically the same results will be achieved by using equations (16) and (25) for M_o or the corresponding equations derived by Bugov.

In Fig. 9 the bending stress σ_o in the section A-A is plotted against the varying wall thickness. It is evident that with the same flange dimensions and the same shaft diameter the wall thickness s has practically no influence on the bending stresses in the section A-A. Vocke[6], by using a very accurate and elaborate formula (without any assumptions made to simplify the problem), has arrived at the same conclusion for pipe flanges with full-face contact. The conditions, however, will alter considerably when the flanges are

free to deflect under the action of the load, that is, without a balancing radial moment at the outer part of the flange. For the sake of comparison this case has also been included, and the stresses in the section *A-A* are calculated according to three methods: (a) Timoshenko's equation (3); (b) the formula of the Swedish Pressure Vessel Committee, which has the following form:

$$M_o = \frac{P(r_2 - r)}{2\pi r} \times \frac{m}{m^2 + (m-1)^2 + \frac{1}{2 \cdot 2}\left(\frac{h}{s}\right)^3 \frac{\log_e \alpha}{r\beta}} \quad \ldots (35)$$

(c) Waters and Taylor "Modern Flange Design."

As shown in Fig. 9 the plotted curves do not differ much for dimensions usual for turbine shafts. Furthermore, it can be seen that the difference in stress between a free-deflecting flange and one having full-face contact is very great at smaller wall thicknesses but decreases at increasing thickness.

Calculation Method III Compared with Methods I and II

Assuming for the flange in the numerical example a bolt load of about four times the tensile force in the shaft or a corresponding tensile stress of 1,000 kg/cm² in the sectional area at bottom of thread, it will be found that, at linear pressure distribution, the bolts cannot keep the flanges in full-face contact. The joints will open up at a distance of about 20 cm from the outer edge of the flange, because the bolts are positioned comparatively near the outer edge. It is therefore appropriate to calculate the bending stress at the section *A-A* according to Method II.

If the bolt dimension, however, is decreased from 16·5 to 12·5 cm and the bolts increased to 30 instead of 20, it will be possible to locate the bolts in the manner shown in Fig. 7. With a bolt stress of 1,000 kg/cm² full-face contact will be obtained and the bending stress will diminish from 236 to 53 kg/cm². The allowable torque stress will thereby be increased from 373 to 418 kg/cm² with an assumed yield point of 3,000 kg/cm² and $S=4$. With the flange structure thus determined it would be possible to increase the torque by about 10%.

The curves showing M_o and σ_o calculated according to Method III have also been plotted, as shown in Figs. 8 and 9.

As the extension of the bolts is much greater than the compression of the flange the stress in the pre-tightened bolts will not be much less than the maximum bolt stress, in this case about 5%.

By constructing the deformation triangles according to Rötscher, it will be possible to study more closely the relation between the maximum bolt load and the pre-tightening bolt load.

EXAMPLE A: FORGED SHAFT WITH A DIAMETER OF 970 MM REPLACED BY A WELDED TUBULAR SHAFT AND INTENDED FOR A KAPLAN TURBINE. FIGS. 10 AND 11.

The shaft for the Bratsk installation has a comparatively moderate axial load—900 tons—in relation to the shaft diameter, owing to the fact that it is coupled to a Francis runner. With a Kaplan turbine the conditions with regard to axial load are more disadvantageous, for at a given shaft diameter the axial load for a Kaplan turbine is about three times as large as for a Francis turbine. The dimensions of a tubular shaft equivalent to the forged shaft shown in Fig. 10 are given in Fig. 11. The axial load is assumed to be 1,000 tons. The other data for the two shafts are given in Table II.

A diameter of the tubular shaft 1·3 times that of the forged shaft has been chosen for the following reasons:

(a) To afford access to the sealing box placed underneath the oil-lubricated guide bearing.
(b) To avoid increasing the bearing losses as compared with those of a bearing the running surface of which has a diameter of about 1·25–1·30 times the nominal diameter of the forged shaft.

It is true that in the Bratsk turbine the diameter of the tubular shaft is 1·40 times the diameter of the forged shaft, but in the Soviet Union water-lubricated rubber bearings are commonly used, with the sealing box easily accessible above the guide bearing.

Because of the large axial load in relation to the size of the shaft the flanges in this case are rather large, entailing a weight equal to that of the forged shaft. An essential increase of 43% in flexural rigidity, however, will be obtained.

The determination of the shaft and flange dimensions has been made in accordance with Method III under the assumption of linear pressure distribution in the joint.

EXAMPLE B: FORGED SHAFT WITH A DIAMETER OF 970 MM REPLACED BY A WELDED TUBULAR SHAFT AND INTENDED FOR A FRANCIS TURBINE. FIGS. 10, 12 AND 13.

The forged shaft for this alternative differs from the one shown in Fig. 10 only in that the bore has a diameter of 200 mm instead of 300 mm, whereby the weight and the torque are somewhat increased. The equivalent tubular shaft has a weight of only 13·5

TABLE II

Type of shaft	Shaft weight tons	I	W_p	n	d	σ_d	σ_o	σ_z	σ_s	S	M_r	P tons
Forged shaft φ970/300. Fig. 10.	25·0	$4{\cdot}31 \times 10^6$	$0{\cdot}178 \times 10^6$	16	14·5	950		700	2,700	4·0	68×10^6	1,000
Welded tubular shaft φ1,260/1,060. Fig. 11.	25·0	$6{\cdot}18 \times 10^6$	$0{\cdot}195 \times 10^6$	20	17·5	1,300	126	700	3,000	4·1	68×10^6	1,000

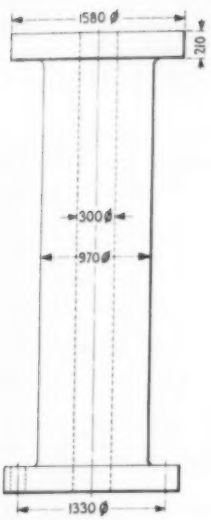


FIG. 10

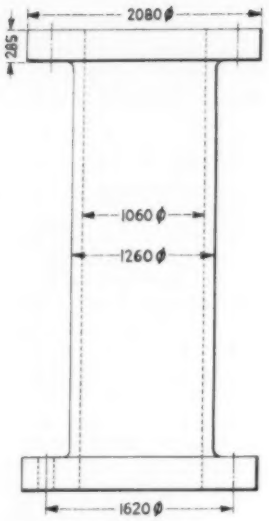


FIG. 11

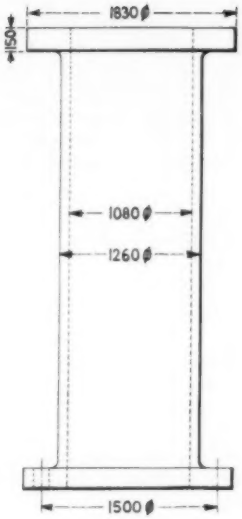


FIG. 12

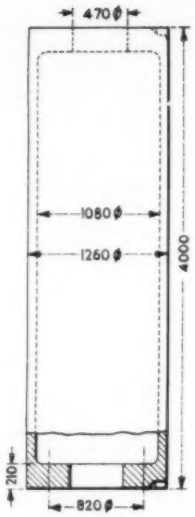


FIG. 13

tons, or about half the weight of the forged shaft. The flexural rigidity increases by about 30%. The axial load is assumed to be 300 tons. Data for this shaft are given in Table III.

For this alternative it would also be possible to design the flanges inwards as shown in Fig. 13. With the flanges made in such a way essential advantages from a design point of view can be obtained. The guide-bearing support, the lower oil container, and the shaft sleeve can be made integrally without expensive split joints. It is obvious that with an inward flange the inner diameter must be large enough to enable a fitter to get into the shaft in order to ream the bolt holes and pull the bolts up with special tools.

Though the shaft is vertical, lateral forces may act upon the shaft, and it is evident that the joint for an inward flange has less resistance against bending stresses due to lateral forces than an outward flange. Furthermore, the joint pressure decreases by the action of axial load towards the outer diameter of the shaft, contrary to the case for an outward flange. The bolts must therefore have such dimensions that ample margin is available for such a pretightening force, and that the joint pressure at the outer edge of the flange is greater than the maximum bending stress in the joint that can be expected by the action of lateral forces.

The flange is calculated according to Method III, and from Table III it can be seen that the maximum bolt stress is only $\sigma_d = 800$ kg/cm² at a joint pressure of $p = 0$ kg/cm² at the outer edge of the shaft. Providing the bolts are pulled up with a force corresponding to a bolt stress of $\sigma_d = 1{,}200$–$1{,}300$ kg/cm² a substantial joint pressure will be obtained, so that, should lateral forces occur, the joint does not open up.

In order to transmit the torque from flange to flange it will be necessary in this case to insert cylindrical shear pins between the flanges. The shear stress in the bolts would otherwise be higher than the conventional maximum allowable working stress of 450 kg/cm².

Conclusions

A turbine shaft is an important part of a generating set, and welded joints in the design of shafts must be introduced with the greatest caution, as a fracture of this part would lead to serious consequences.

In the Soviet Union the following clauses have been worked out with a view to arriving at some conclusions regarding the reliability of welded shafts, and also to give directions for research work:

TABLE III

Type of shaft	Shaft weight tons	I	W_p	n	d	σ_d	σ_o	σ_z	σ_s	S	M_r	P tons
Forged shaft ϕ970/200. Fig. 10.	26·0	$4{\cdot}34 \times 10^6$	$0{\cdot}179 \times 10^6$	16	14·5	285		210	2,700	4·0	70×10^6	300
Welded tubular shaft ϕ1,260/1,080. Fig. 12.	13·5	$5{\cdot}69 \times 10^6$	$0{\cdot}180 \times 10^6$	20	11·5	780	40	520	3,000	4·35	70×10^6	300
Welded tubular shaft ϕ1,260/1,080. Fig. 13.	13·0	$5{\cdot}69 \times 10^6$	$0{\cdot}180 \times 10^6$	12	12·5	800	80	500	3,000	4·30	70×10^6	300

1. Investigation of the fatigue strength of the welds in running shafts.
2. Investigation of the resistance of large tubular shafts to torque.
3. Technological questions—
   (a) Investigation of different steels, economical in welding and possessing high mechanical properties.
   (b) Investigation of joints with different as well as similar materials welded together (cast, forged and cast, rolled).
   (c) Selection of electrodes and welding procedures to ensure uniform strength of the welded joints.
   (d) Procedure and methods of heat treatment.
   (e) Test and inspection methods of the welded joints.

Tests with model shafts made on a small scale 1 : 10 and 1 : 15 are valuable to measure the stresses and to find out how they agree with the different formulae. They do not, however, give satisfactory answers to the technological questions put forward for a full-sized shaft because of the influence of the reduction factor. Therefore fatigue tests have been made at the Paton Institute on model shafts at half scale. Lastly also, experimental shafts have been manufactured for tests in actual installations. These are made according to different methods and with different steels. One has the shaft body made as a forged tube united to flanges of cast steel. The material in the tube and the flanges is of high-quality steel with good welding economy and possessing higher mechanical properties than the steel generally used for forged shafts. One is made of rolled-steel plate united to flanges cast in permanent moulds, in order to decrease the necessary machining allowance. The third experimental shaft differs from the latter only in that the materials in the tube and the flanges have very similar properties.

Even if the impulse to manufacture welded shafts was caused by the difficulties involved for the steelworks in the production of the enormous shaft dimensions to be found in the Soviet Union, there is no reason why this method could not also be used for shafts of more moderate dimensions. This is shown by examples A and B. This is particularly evident in Francis turbines, where a welded tubular shaft will be 50–60% as heavy as a forged shaft for the same torque.

It is estimated in the Soviet Union that in a five-year period a saving in steel consumption amounting to 2,800 tons for turbines in production will be obtained, which is equal to a saving in cost of about six million roubles.

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Appendix I

Equation (14) gives

$$P_{tm}t_1 + P_{tm}\frac{t_3/2 + \Delta}{2} = P_{pm}t_2 + P_{pm}\frac{t_3/2 - \Delta}{2}$$

i.e.
$$\frac{P_{pm}}{P_{tm}} = \lambda = \frac{t_1 + t_3/4 + \Delta/2}{t_2 + t_3/4 - \Delta/2} \quad \ldots (31)$$

From equations (18 and (31)

$$\lambda = \frac{t_1 + t_3/4 + \Delta/2}{t_2 + t_3/4 - \Delta/2} = \frac{t_3/2 - \Delta}{t_3/2 + \Delta} = \frac{1 - 2\Delta/t_3}{1 + 2\Delta/t_3}$$

i.e.

$$\frac{1 + \lambda}{1 - \lambda} = \frac{t_1 + t_2 + t_3/2}{t_2 - t_1 - \Delta} = \frac{t_3}{2\Delta} \quad \ldots (32)$$

equation (32) gives

$$\Delta = \frac{t_3}{2}\frac{t_2 - t_1}{t_1 + t_2 + t_3} = \frac{t_3}{2}\frac{t_2 - t_1}{T} \quad \ldots (33)$$

substituting the value of Δ from equation (33) into equation (18)

$$\lambda = \sqrt{\frac{t_3 + 2t_1}{2t_2 + t_3}} \quad \ldots (34)$$

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BEAMA Annual Report

THE Fiftieth BEAMA Annual Report for 1960–61 shows that the British electrical industry has continued to expand and that its annual output is now worth over £1,600 million. In particular the production of generating plant reached a new record figure of 5,146 MW capacity, of which some 36% was exported. Exports to North America accounted for at least one-third of the total. An interesting feature of the report concerns the advances made in the thermal-power field; estimates of the cost of the large 550-MW sets to be installed in 1963 are put at £40/kW of plant installed, which is a reduction of 20% on the estimated average of £50/kW in 1960, and it is stated that these sets are expected to attain a thermal efficiency of some 36%. It is also claimed that the costs of nuclear power are falling at an even faster rate.

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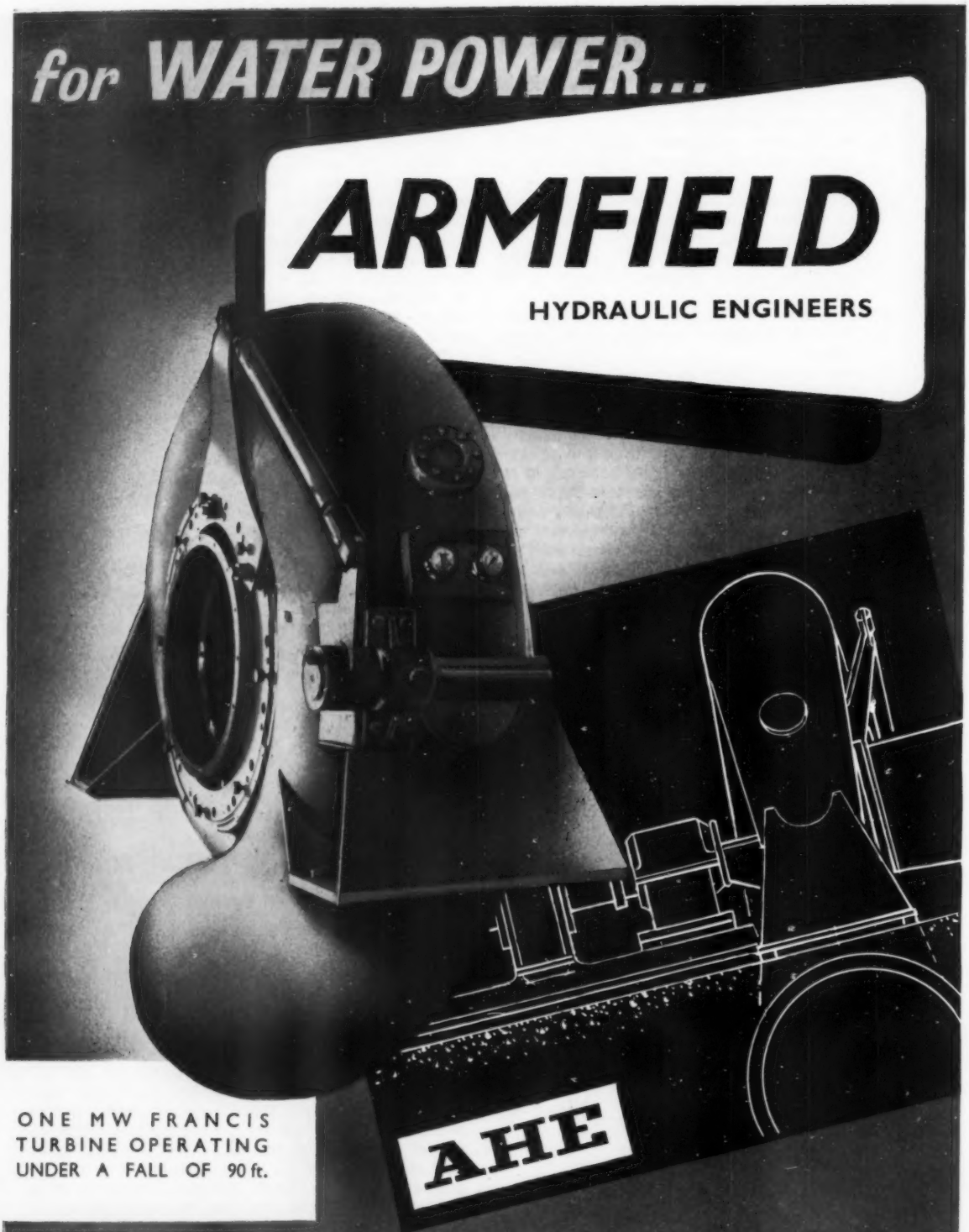
HYDRAULIC ENGINEERS



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Waterproof-Lining Material

Use of Famliner as a river-bank-lining material

A waterproofing material known as Famliner has been developed by F.A. (Membranes) Limited of St. Helens, Lancashire, and is claimed to be applicable to the lining of channels, river banks and small reservoirs. Famliner consists of a ½-in thick bituminous core reinforced with chicken-wire mesh, and which is faced on both sides with a Fibreglass tissue. The core consists of bitumen and filler materials, the latter containing an additive of Fibreglass to give additional rot-proof qualities. The facing material is designed to prevent creeping of the bituminous core and to give a surface of uniform strength.

The lining is supplied in sheets 3 ft wide by a maximum length of 12 ft. The average weight of the material is 32 lb/sq yard thus giving an overall weight of 128 lb in a 12 ft long sheet. A sheet is therefore portable by two or three men when being loaded and unloaded to and from transport, and when being carried on the site. The size of the sheets also permits them to be carried easily in transport of limited dimensions, and the low weight of the material allows it to be transported to sites that are inaccessible to heavy equipment, such as that required for large-scale concrete laying.

To prepare the material for laying, a sheet is laid on the ground, and the areas that are to be overlapped by other sheets are brushed with a hard brush to remove the protective talc with which they are coated on leaving the factory. The sheets are, for most purposes, overlapped 6 in at the ends and edges. In certain cases a greater overlap may be required. When the talc has been removed the lap areas are flamed over with a propane-gas torch and a priming coat of hot bitumen of the R95/25 type is applied with a brush. The sheets are then laid in position and both overlapping areas are again played over with a gas torch to soften the priming bitumen. Hot bitumen from a can is poured between the laps, and the sheets are bonded together by foot pressure. The seal between sheets bonded by this method is claimed to be immediate and completely waterproof. The exact laying pattern to be adopted will vary from one type of application to another, but the makers intimate that they will be pleased to give advice on this point.

It is necessary to anchor the top of the Famliner sheets in position to prevent possible movement of the lining. This can be done by excavating a small V-trench at the top of and slightly behind the channel bank, and tucking the end of the sheet into it. The trench is cut so as to provide a berm, over which the sheet may be taken into the trench. In some cases anchoring of the sheets with wedge-shaped pegs (18–24 in long), driven through the laps, may be advisable in addition to the trench method of anchoring. After the sheet has been placed in the trench, the excavation is backfilled. The toe of the sheet may also be anchored by either burying it in a trench or anchoring it with pegs, or a combination of both. For reservoir work, or for the complete lining of canals, in which work the lining is taken from one bank to the other, the question of anchoring at the toe does not, of course, arise. For work on river banks, particularly where there is an erosion problem, other methods of toe anchoring may have to be considered.

The base on which the sheets are laid should be cleared of any weed growth and a solution of weed killer applied. Compaction of the earth is required only to the extent necessary to prevent local settlement. Famliner is stated to conform readily to the overall contours of the base but cavities of small dimensions should be avoided. The material is claimed to have an indefinite life from the point of view of weathering and ageing, and is stated not to be affected to any great extent by sunlight and to be able to withstand successfully the attacks of the normal acid and alkali contents of soils. Famliner has already been employed as a lining material for reservoirs and river banks, and it is suggested by the makers that the material has possible uses as a lining for earth-dam faces and as a replacement for clay cores in such dams.

Additions to Smith 12 Excavators

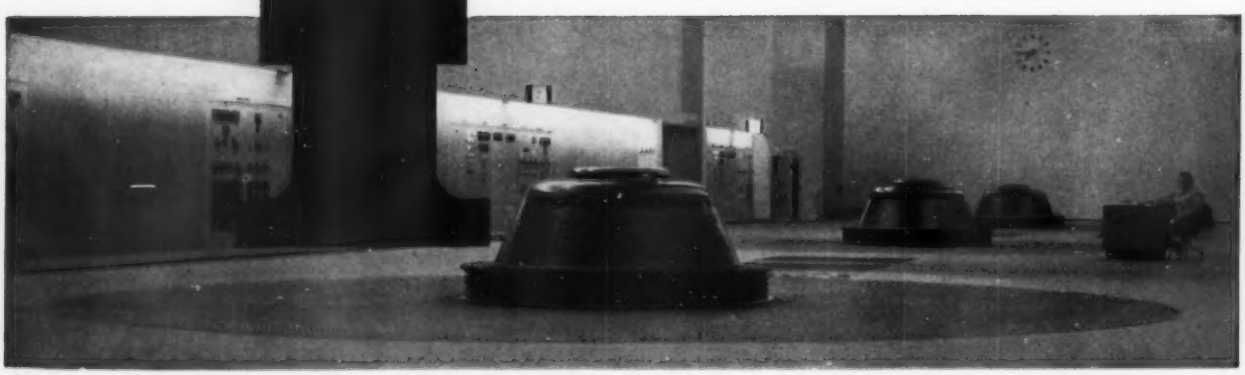
Thomas Smith & Sons (Rodley) Limited, of Rodley, Leeds, England, have announced that an independent high-speed derrick unit and a swing brake are now available for the Smith 12 excavators and crawler cranes. These two units are intended to enable the machine to hoist, slew and derrick simultaneously, and, if they are used in conjunction with the special

Power Stations and Substations

Sécheron Works Co Ltd, Geneva, the specialists in the electrotechnical field, supply all kinds of equipment for complete power stations and substations:

High capacity A.C. and D.C. motors and generators. Power transformers of all sizes and voltages. Automatic regulators for various types of controls. Pumpless mercury arc rectifiers, semi-conductor rectifiers.

Further lines of production: Electric traction equipment, Welding sets and electrodes.



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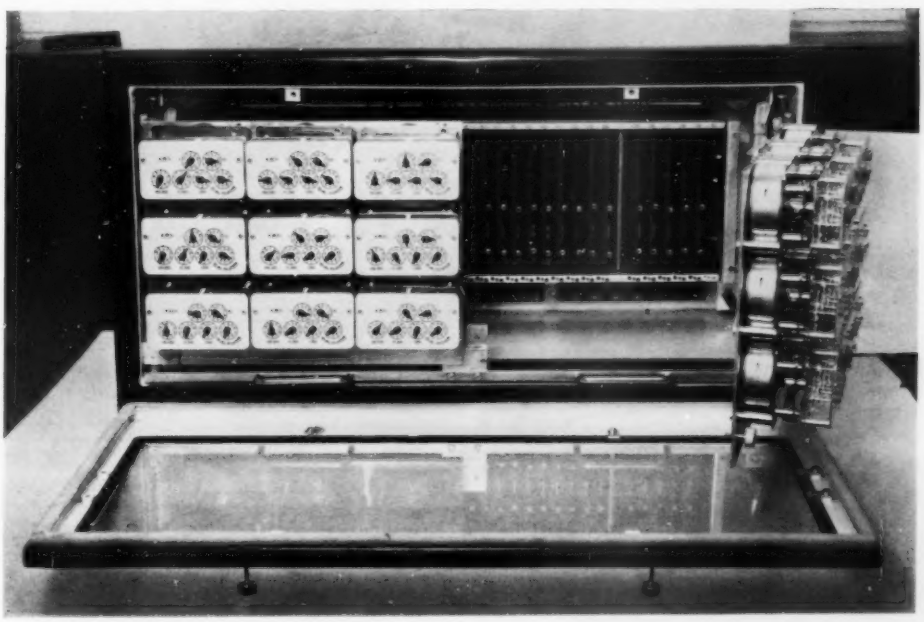
Sécheron

S.A. des Ateliers de Sécheron, Geneva 21, Switzerland

planetary-load-lowering drum unit that is also available, it is stated that they will complete the equipment for transforming the Smith 12 into a sensitive precision crane. All this equipment is now available in the form of optional extras on new machines.

The derrick unit comprises a totally enclosed worm-driven drum unit, which is powered from the first machinery shaft by spur gearing through a pair of friction clutches, all of which is encased and uses the basic machinery oil flow for lubrication. Also incorporated in the design is an automatic brake, which is fitted with an interlock device to prevent the clutches being applied if the brake becomes out of adjustment. The control for the independent derrick unit is of the dead-man's-handle type. The hand-operated swing brake is fitted to the first-machinery-shaft clutch disc, which controls the drive to the slewing motion. This brake is of twin-shoe construction, and is very light in operation, although it is claimed to be sufficiently powerful to hold the machine on any slope.

Electronic-Summation Metering Equipment



Typical Ferranti electronic summator

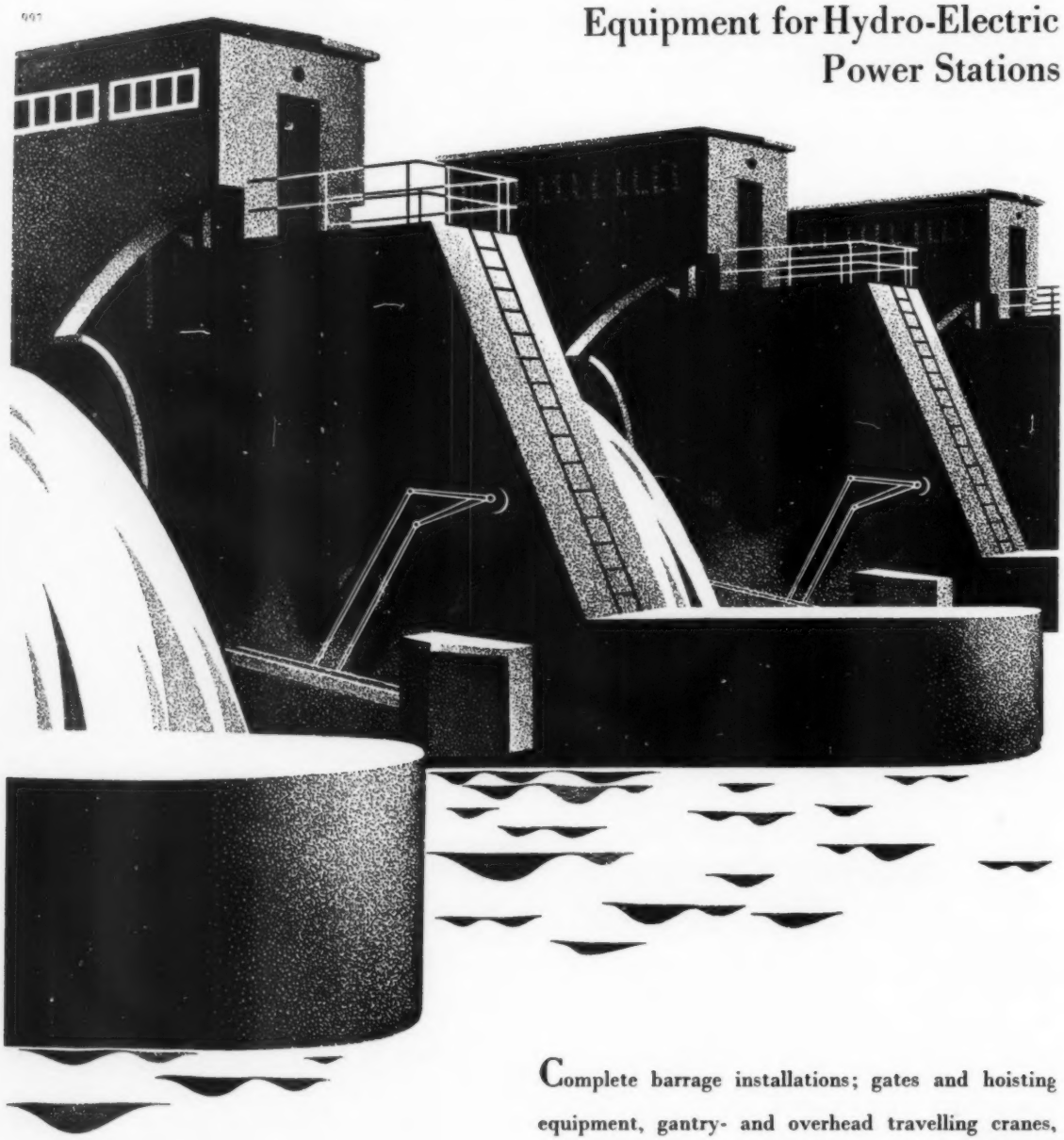
Ferranti Limited, of Hollinwood, Lancashire, England, have introduced electronic-summation metering equipment for use in power stations, substations and other bulk supply points. The main feature of this equipment is the replacement of electromechanical summation by electronic methods. The conventional mechanical contactors fitted to watthour meters are also replaced by photoelectric devices. It is stated that, although this new equipment may eventually supersede electromechanical equipment, it is completely compatible with it. In effect, the electronic equipment can drive existing electromechanical equipment and vice versa.

It was considered when designing the summator that 16 channels would be adequate for most summation-metering schemes. A maximum-demand indicator of the single-revolution type can be supplied either in the summator case, where the number of channels permits, or in a separate case of smaller dimensions. As the entire summator is transistorised—all the circuit functions are provided by printed cards—the cubicle space has been reduced to something less than a quarter of that occupied by conventional electromechanical equipment. The rack for the printed-circuit cards, most of which comprises bistable flip-flops, binary dividers and NOR gates as basic logical units, is located at the rear of the case. The register dials are mounted on hinged plates at the front, allowing easy access to the printed cards. All components used on the printed cards are type approved to recognised service specifications.

Briefly, the summator stores on display registers, incoming pulses, coincident or otherwise, from a number of channels and totals all the pulses on a totalising binary register. Incoming pulses, which are stored in transistor flip-flops as binary digits, are passed on sequentially to a second set of flip-flops actuating an impulse-driven stepping motor, which advances one step on each reversal of current drive. These reversing impulses produce a forward step-by-step rotation of the rotor, and through gearing indicates the kWh registration on the dials. The output from the final flip-flops is differentiated and fed into a common highway in sequence to a totalising register.

When it is necessary to indicate net power, this service can be provided by means of a reversible binary

Equipment for Hydro-Electric Power Stations



Complete barrage installations; gates and hoisting equipment, gantry- and overhead travelling cranes, trash screen cleaning machinery; sluice gates; control valves for high pressure conduits; automatic safety organs for pipe lines; discharge regulating valves, rotary valves with rotary-piston servomotors, needle valves, butterfly valves, high pressure fittings, piping systems for oil and cooling water plant; funicular and aerial cableways for passenger and goods transport; building machinery for dam-building work.

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counter and logical gating. The former is a device that can increase or decrease its content by one depending upon which of its inputs is pulsed. In effect, the two highways, generated power and auxiliary power, would be feeding each of the two inputs. In general the highway having the greater pulse rate would be finally feeding a net register, but only after the negative or auxiliary pulses in the counter store are cancelled.

The equipment is stated to be extremely flexible, and modifications or additions to existing schemes can be effected without withdrawing the equipment from site. Another facility of the summator is that subtotal registers can be provided together with printometer outputs.

Among the advantages claimed for the electronic summator over the electromechanical type are a high rate of impulsing (10/sec compared with 1/sec), the complete absence of mechanical driven parts, and a low power consumption. A typical 16-channel summator is said to require not more than 16 W, and thus no ventilation of the summator case is required.

Abstracts from the World Technical Press

Pressure-Shaft Lining

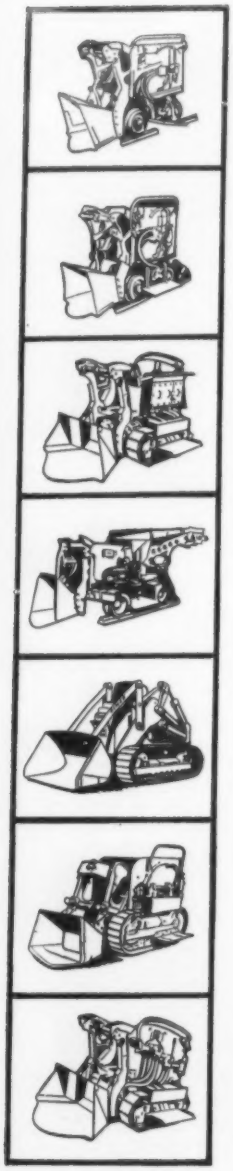
In high-head hydro-electric developments, pressure shafts, which are generally reinforced by some form of lining, tend to supersede the conventional surface or buried penstock as a link between surge tank and power house, assuming, of course, that suitable geological conditions are available. This paper describes the experimental tests carried out in 1957 by Escher Wyss with a view to determining the correct design for the pressure shaft of the Nendaz power station, which is part of the lower stage of the Grande Dixence development. The testing gear consisted of a closed cylindrical pipe, representing the shaft lining, and the measuring equipment for ascertaining the radial, axial and tangential expansion of the pipe, the circumferential stretching of the concrete, and the incoming and outgoing quantities of water used in the tests. The most suitable material for the test pipe was thin sheet metal with high elongation values, a high yield point, and a degree of elasticity sufficient to enable a substantial portion of the load to be transferred to the surrounding concrete and rock. The actual test lining, 3 m in diameter by about 15 m in length, consisted of an upper and a lower half, 25 mm and 15 mm in wall thickness respectively, the lower half of the cylinder being reinforced by hoops 190 by 25 mm in cross section. The surrounding concrete had a thickness of about 50 cm in the 7-m long middle part of the lining, and about 120 cm at either end, the whole cylinder being thus divided into four measurement sections, which could all be tested simultaneously. The measuring equipment consisted of bellows-type dilatometers set at an angle of 120° to each other in each of the four sections of the test lining, and which were used to determine its radial expansion, an elongation measuring rig for each of the two halves of the cylinder, and strain gauges fitted in all four sections in axial and circumferential directions. Other instruments were used to measure the peripheral expansion of the surrounding concrete in all four tested cross sections, and also to gain additional information on the properties of the rock while construction work was in progress. The equipment and the testing procedures are described in detail, and the results are analysed in separate paragraphs for lining expansion, load distribution between lining and surrounding material, stresses in the lining, and conditions in the surrounding concrete and rock. A comparison of the results obtained in each of the four sections of the test cylinder enabled the most suitable shaft cross section to be determined. Altogether, the Nendaz tests provided valuable information on the combined effect of steel lining, concrete and rock in a length of full-size test shaft. (A. Surber, *Escher-Wyss News* (English Edition), Vol. 32/59, No. 1.)

Side-Channel Spillways

Calculating backwater and drawdown curves along a side-channel spillway by conventional methods is a very lengthy procedure. Proceeding from the studies carried out by Engels, Faure, de March and Gentilini, the author of this paper examines the possibility of shortening this procedure in the case of trapezoidal channels, by first determining general backwater and drawdown curves. These are essentially derived from the integration of Faure's differential equation for discontinuous flows. Of the assumptions made, only the balance between friction and gravity forces does not appear quite reliable. Measurements taken in this connection by Gentilini show, however, that this particular assumption is justified in the case of smooth flow and for a side-channel spillway of moderate length. The derived formulae, therefore, are not fully accurate for shooting flow, but enable the shape of the water level and the influence of the Froude number to be approximately defined. The procedure followed by the author in the calculation for a side-channel spillway with shooting flow is explained by means of an example. The discharge capacity of the side-channel spillway can be improved above all by increasing the water depth in the lower part of the spillway, and reducing at the same time the Froude number. The insertion of a submerged weir in the tailwater is a very simple measure, which, under given circumstances, can be applied to existing structures. (Dr. Ing. D. Vischer, Motor-Columbus AG, Baden, *Schweizerische Bauzeitung*, Vol. 78, No. 49, December 8, 1960, p. 789 5 pp., 5 ff., 1 table.)

Whitehorse Rapids Development

This development, located about one mile upstream from the City of Whitehorse on the Yukon River, utilises a catchment of 7,500 sq miles, which comprises the headwaters of the Yukon River (formerly called the Lewes River). After extensive river-stage and discharge measurements, the decision to proceed with the scheme was made in August 1956, and the first unit began to generate power for the local system on November 15, 1958. The main structures of the



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development, which, with the construction work, are described at length, are: (a) a conventional earthfill dam with two 40-ft wide sluice openings and one 12 ft 6 in wide regulating sluice; (b) the headrace canal, the downstream end of which is founded mainly on pervious gravels, so that an impervious lining was necessary; (c) the three-conduit intake, with head gates and screens installed for two conduits only, the third conduit for the future unit being closed off by a bulkhead in the penstock; (d) the three penstocks, all installed at the outset so as to avoid breaching the canal embankment when the third unit is added; (e) the power house, the excavation for which was completed for all three 7,500-h.p. Kaplan-turbine-driven units, the substructure being built for the initial two units only. A two-transformer step-up substation is located adjacent to the power house. Fishway facilities consist of a barrier dam about 200 ft upstream of the main rapids, a collection system and transportation channel at the power house, a fish ladder and a concrete box culvert through the dam. (L. A. Carey, *The Engineering Journal*, Vol. 43, No. 10, October 1960, p. 81, 6 pp., 5 ff.)

Extensive Rockbolting at Hills Creek Dam

The main purpose of this rockfill structure, which was designed by the Corps of Engineers and is described at length, is to provide additional flood-control potential for the Willamette River basin. It is an 11-million cu yard, 346-ft high gravel and rockfill dam which will store 356,000 acre ft of water. 107,000 acre ft will be dead storage, 49,000 acre ft will be used to run the 30-MW capacity power station, and 200,000 acre ft will be reserved for flood control. As a result of the rockbolting experience gained on the 1,150-ft long lined diversion tunnel, which had an equivalent diameter of 23 ft, it was expected that a substantial amount of this type of reinforcement would also be required on the main-dam contract. Accordingly, the project was bid on the basis of 22,000 lineal ft of bolts. However, in the event, more than twice that footage was required. Some 53,000 lineal ft of 1-in diameter rock bolts were used, mostly to stabilise the right abutment. Rock mechanics came into the picture after preliminary core-drilling on a large scale had failed to indicate the severity and extent of the various faults. The methods developed to stabilise the formation, after an analysis of the elastic and structural qualities of the rock, are reviewed. The slopes of the abutment and intake channel were set back to support and confine many of the faulted areas and where possible, these berms were adjusted to fit the faults. The procedures applied to the drilling of the rockbolt holes, and to rockbolting itself, are described in detail. (*Engineering News-Record*, Vol. 165, No. 20, November 17, 1960, p. 44, 4 pp., 6 ff.)

Peruća Plant Commissioned

The two 20·8-MW generating sets of this Yugoslav plant on the Cetina River were put into service on November 25, 1960. A rockfill dam, 63 m high, 450 m long at the crest, creates a reservoir of 540 million m^3 capacity. This plant constitutes the first stage of the Cetina basin development, and the Peruća reservoir will soon be able to ensure the regulation of the discharge operating the 342-MW power station at Split, about 20 km farther downstream. Construction work at the Split plant has advanced so far that the first half of the generating equipment is expected to be on the line in the very near future. Peruća, together with Split, will then be in a position to add almost 2,000 million kWh a year to Yugoslavia's energy production. (*Energija*, Vol. 9, No. 9/10, 1960.)

Transmission Lines

This paper defines the mechanical design of transmission lines and shows how the cost of transmission of electrical power is dependent upon the method of generation. The development of power transmission in New Zealand is discussed, and the various factors affecting the mechanical design of a transmission line are considered. The effect of the two most important factors, wind load and broken-conductor load, are examined. The recent overseas research work on the former is reviewed and applied to New Zealand conditions. A test on a prototype conductor to measure the load applied to a tower by a broken conductor is described. The paper details the wind loading and broken-conductor loading now used as the design basis for the towers included in long-span transmission lines, and shows how a reduction in cost of the order of 7% has resulted. (E. B. Mackenzie, *New Zealand Engineering*, Vol. 15, No. 10, October 1960, p. 369, 7 pp., 5ff.)

Better-Construction Seminar

This is a report on the seminar held by the Australian Institute of Builders at Canberra on May 11–13, 1959. The six papers read dealt with Better Education, Better Design (2 papers), Better Methods, Better Materials, and Better Management, and examined the contribution of each of these factors to better construction. (*New Zealand Engineering*, Vol. 15, Bo. 10, October 1960, p. 375, 4 pp.)

Canal Linings and Dam Facings

This special issue of the undermentioned journal reprints the papers presented at the colloquium held in Paris on May 12 and 13, 1960, by the French Committee on Large Dams. The first six papers are devoted to the various types of canal linings, their conception, structure and execution. The final section of the issue deals with impervious facings in rockfill and earthfill dams, and covers the following papers: No. 7, "General Considerations of Dams Built Abroad with Upstream Impervious Facings," by Ch. Laroche; No. 8, "Impervious Facings in Rockfill Dams Built by Electricité de France," by Y. Le May; No. 9, "The Impervious Facing of the Paradela Dam, Portugal," by H. Vidal; No. 10, "Algerian Dams with Upstream Facings of Bituminous Concrete," by J. Thévenin. A summary of the debates is followed by the general conclusions drawn on impervious facings by a special subcommittee of the conference. Two types of rockfill are considered: rockfills containing only a very small proportion of small-size rock, tipped and strongly sluiced, and rockfills consisting mainly of small-size rock of possibly moderate quality, and mechanically compacted. In structures of the first type, very simple facings will prove adequate in dams up to 50 m high, and fairly simple facings will do up to 90 m, but great precautions are required at 114 m; in any case, flexible facings or special toe joints must be provided. With compacted material, only slight settling will occur even in very high dams; simple facings should

therefore prove efficient although drainage becomes a problem. No experience is available with facings of bituminous concrete on high deformable structures built of tipped rockfill. However, experience on Algerian dams built of compacted material shows that: (a) a stable bituminous facing is possible on slopes with a batter between 1 : 1 and 0·8 : 1, but this is a difficult job requiring much care and skill; (b) in structures up to 75 m in height, and in cases of slight settling, impervious bituminous facings have behaved satisfactorily; (c) with regard to the problem of ageing, the particular case of the Ghrib dam under very difficult conditions proved quite reassuring. (*Travaux*, Vol. 44, No. 313, November 1960, 47 pp., 31 ff.)

Brazilian Developments

The undermentioned journal is devoted entirely to hydro-electric developments in Brazil. In addition to descriptions of the Furnas installations (WATER POWER, November 1958, p. 325) and the Três Marias dam (WATER POWER, December 1959, p. 445, January 1960, p. 14, and February 1960, p. 55), it contains the following articles: "Electric Power and Industrial Development in Brazil," a comprehensive survey by Mario Savelli, p. 261, 16 pp., 6 ff., 5 full-page maps in colour; "Brazilian Electrification Programme," by John Cotrim and Luis Carlos Barreto, p. 277, 4 ff., 2 full-page maps in colour; "The Paulo Afonso Plant (Rio São Francisco Development), by Octavio Marcondes Ferraz, p. 296, 10 pp., 10 ff.; "The Urubupunga-Itapura Installations" (Rio Paraná Development), p. 307, 8 pp., 5 ff., by P. Mendes da Rocha and Carlos Eduardo de Almeida; "Experimental Studies of the Salto-Funil Dam" (flood-control spillway, temporary diversion, tunnel, tailrace and bottom outlet), by Fernando Manzanares Abecasis and Fernando de Oliveira Lemos), p. 322, 6 pp., 9 ff.; "The Salto-Funil Project," by J. Laginha Serafim, F. M. Abecasis & Antonio F. Wittnich Carrisso), p. 328, 13 pp., 15 ff. Summaries of all these articles in Portuguese, French and English are given at the end of the issue In addition, a detachable supplement by Rui Humberto Cordeiro, 26 pp., 18 ff., describes in detail the erection work on the HV lines in Overseas Portugal (Angola and Mozambique). (*Electricidade*, No. 15, July–September 1960.)

Hydro Power and Pumped Storage for Peak Loads

An expert of worldwide reputation reviews briefly in this article the role played by hydro power and pumped storage in providing economical daily capacity peaking for electric-power systems. Modern utility system practice in most parts of the USA now calls for putting hydro capacity "on peak," base-load foundation being assigned to the thermal units of the system; this practice becomes more accentuated during low-water periods. A typical instance is the new 800-MW hydro plant at Priest Rapids on the Columbia River, designed by the Harza Engineering Company to operate at a capacity factor of 37·5%; its upstream sister plant, now under construction at Wanapum, will operate at the same capacity factor. The importance of pumped storage for peaking is emphasised, and the three-stage evolution of the equipment involved is reviewed, the latest advance being the completely reversible unit with one generator-motor unit being permanently coupled to a pump-turbine. The economics of pumped storage are summarily discussed. The article concludes with a short description of a rather unconventional scheme, which involves an underground pump-turbine plant using a disused limestone mine as a lower reservoir, and an upper reservoir provided by an existing process-water pond 2,300 ft directly above the mine. This scheme results in the shortest possible penstock (a simple vertical shaft) that will develop the given head, and permits the construction of a high-head pumped-storage scheme in quite flat country. An additional positive factor is that this source is located within a few miles of the load centre of gravity of a large electric utility system. (Richard D. Harza, *Power Engineering*, October 1960, p. 79, 3 pp., 4 ff.)

Energy Dissipation in Submerged Circular Jets

A study of energy dissipation in a high-velocity jet discharging beneath a water surface is discussed. At the instant the jet enters the standing pool, it still has maximum energy, which then gradually disperses as it moves forward into the surrounding medium. The testing arrangement, in which the standing pool is represented by a stilling tank, and the procedure followed, are described. A few previous investigations, undertaken with a view to studying the process by which the energy of the jet decreases to its minimum value, are taken into consideration; the hypothesis that there exists a critical region within which the energy of the jet is reduced to a minimum, was experimentally tested, and found to hold good. The paper also deals with the distribution and magnitude of velocities on the bed of the stilling tank under various conditions of flow. (N. S. Govinda Rao, K. Seetharamaiah, and N. V. Chandra-Sekhara Swamy, *La Houille Blanche*, Vol. 15, No. 6, November 1961, p. 704, 10 pp., 8 ff.)

Penstock Welding Techniques

The welding techniques described in the article reviewed in the February issue of WATER POWER, p. 84, are illustrated in a second instalment by various examples of actual installations. (Jürg Bienz, *La Technique de l'Eau*, Vol. 14, No. 166, October 15, 1960, p. 41, 4 pp., 9 ff.)

CLASSIFIED ADVERTISEMENTS

Announcements for this column can be accepted up to the 8th of the month for the following month's issue. The charges are fourpence per word with a minimum of 10s. Box No. facilities 2s. 6d. extra. In order to avoid accountancy it would be appreciated if instructions to insert were accompanied with remittance.

Displayed classified advertising for situations vacant, situations wanted, public appointments, are accepted at £2 10s. 0d. per column inch.

EDITORIAL ASSISTANT

A YOUNG ENGINEER (25–35) will shortly be required as editorial assistant to this journal. His qualifications and experience should preferably be in civil or hydraulic engineering or in corresponding laboratory work. An aptitude for technical writing is essential and some knowledge of languages would be an advantage. The right candidate would be trained with a view to the eventual editorship. Applications should be addressed to The Editor, WATER POWER, 33 Tothill Street, Westminster, London, S.W.1.

Kelsey Power House during construction.*

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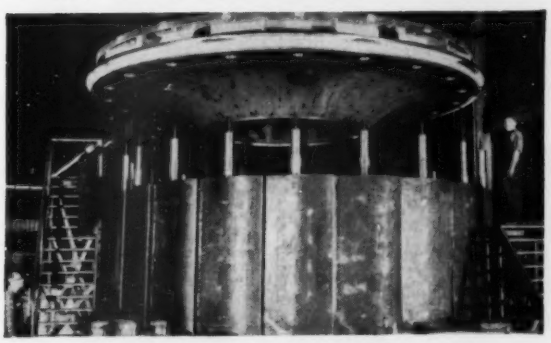
This achievement is particularly remarkable since Kelsey is the largest Canadian power station north of latitude 55°, and the remote location added to the normal difficulties of erection and transportation.

The five Dominion Propeller Turbines at Kelsey have an aggregate rated capacity of 210,000 HP.

Runner, Hub and Head Cover prior to installation.*

Photos courtesy Manitoba Hydro-Electric Board.



Wicket Gate and Head Cover Assembly in the Dominion Plant.

HYDRAULIC DIVISION

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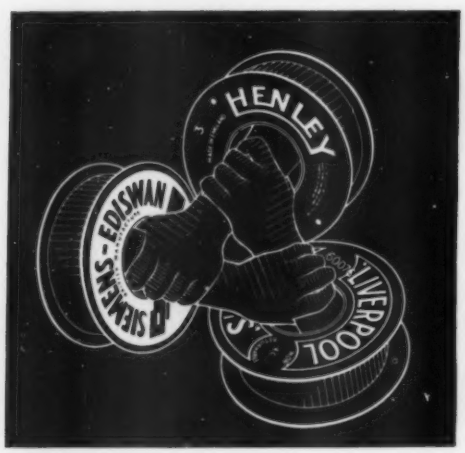

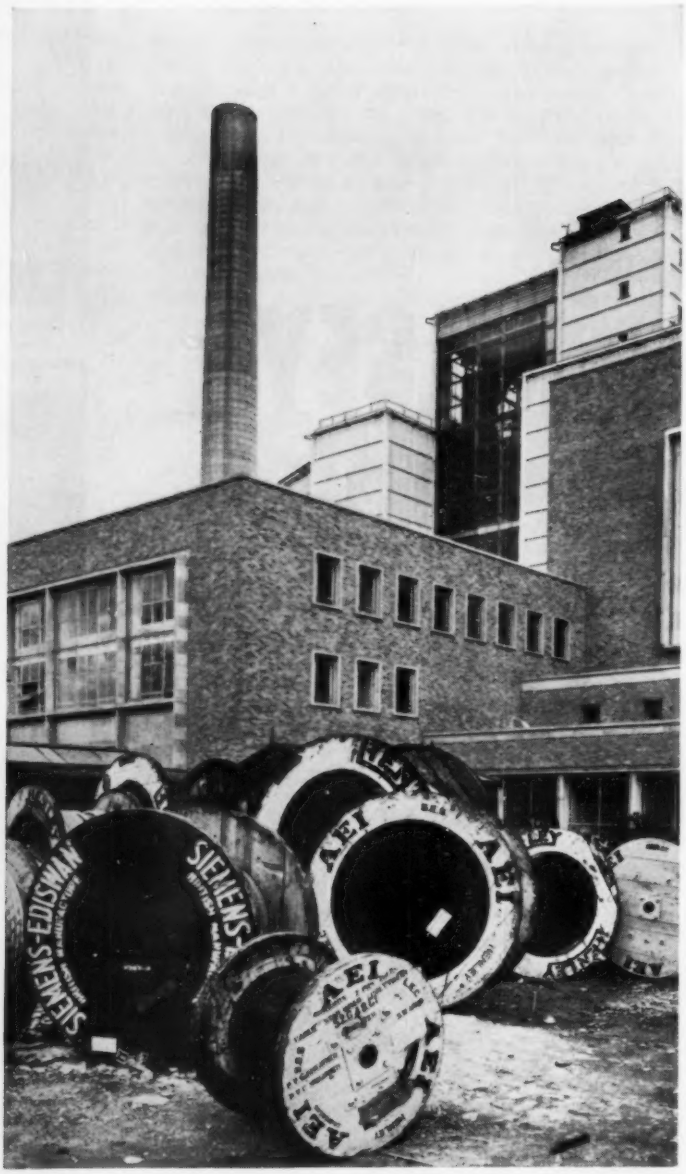

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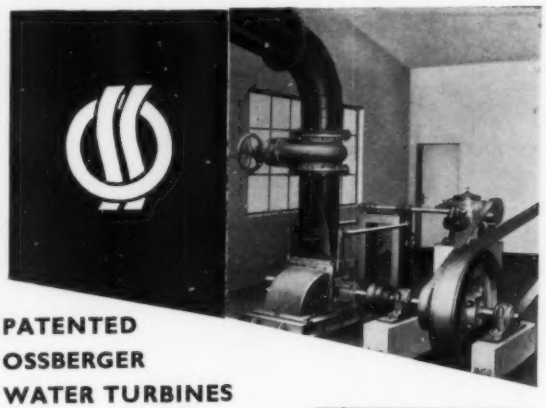

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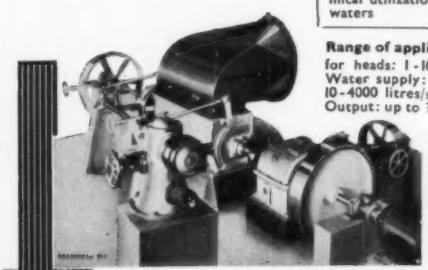

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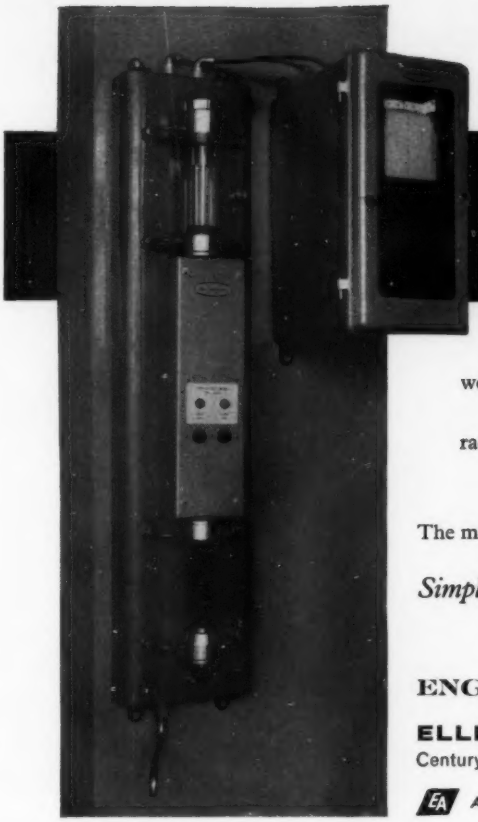

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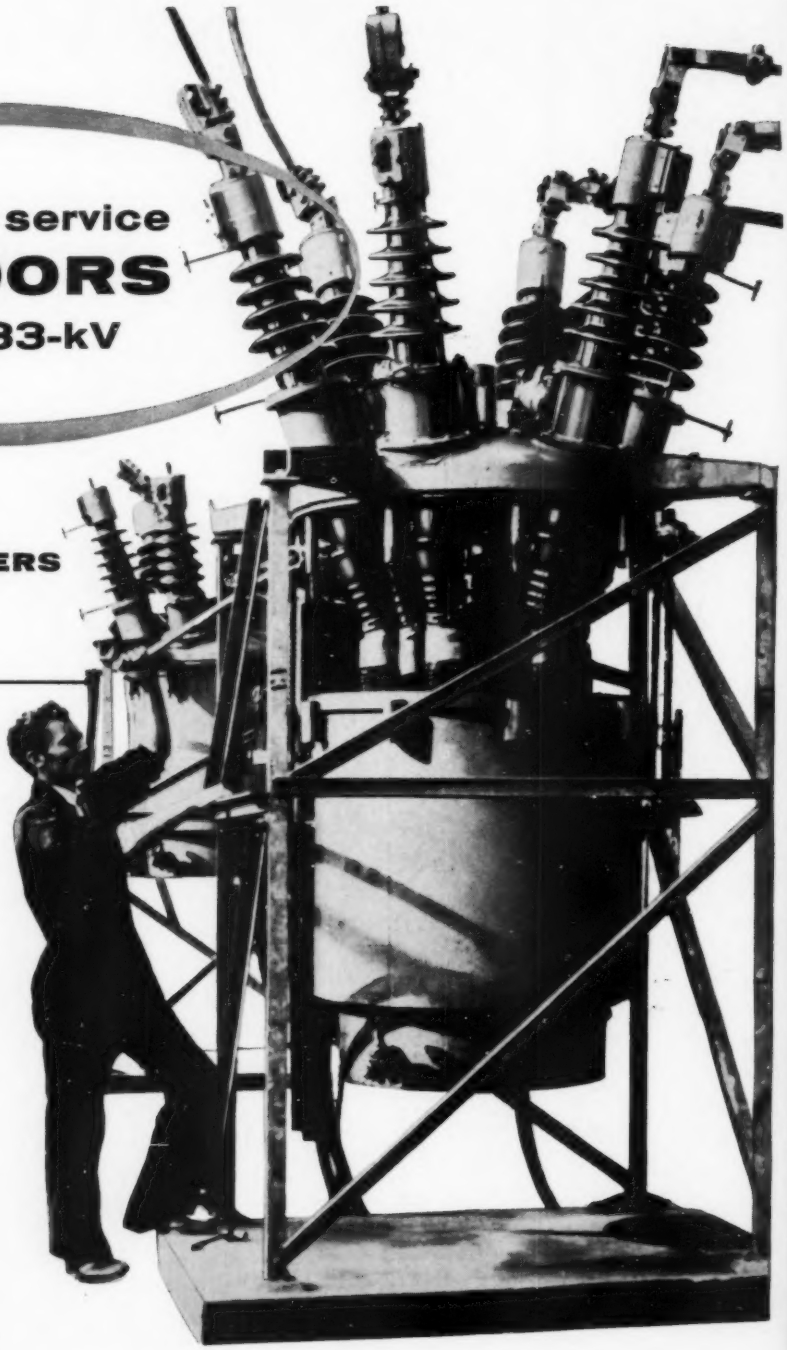

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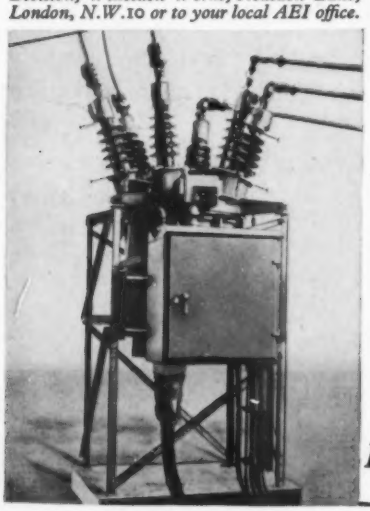

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